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TERMINAL RADAR INTERFERENCE CRITERIA STUDY.(U)
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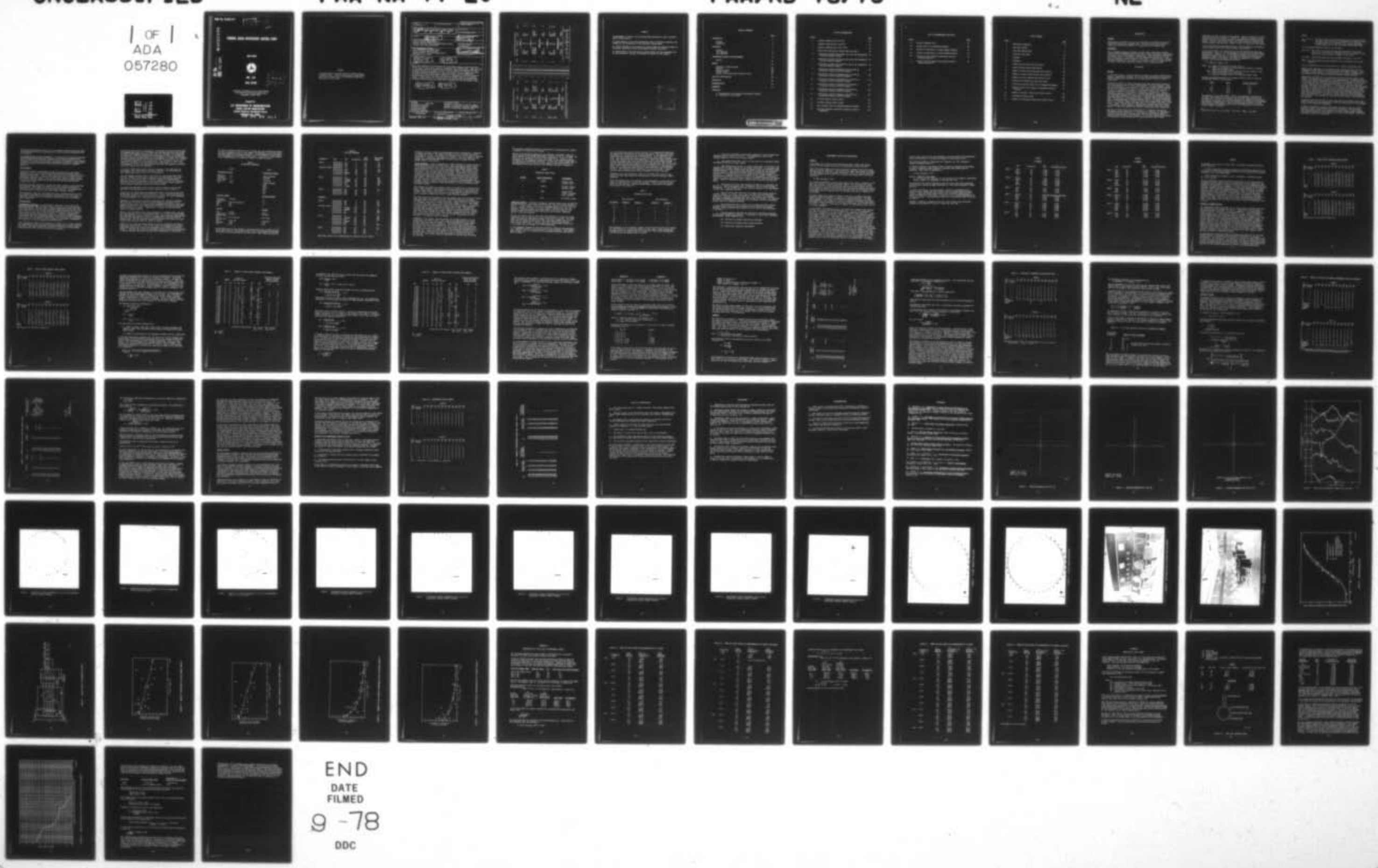

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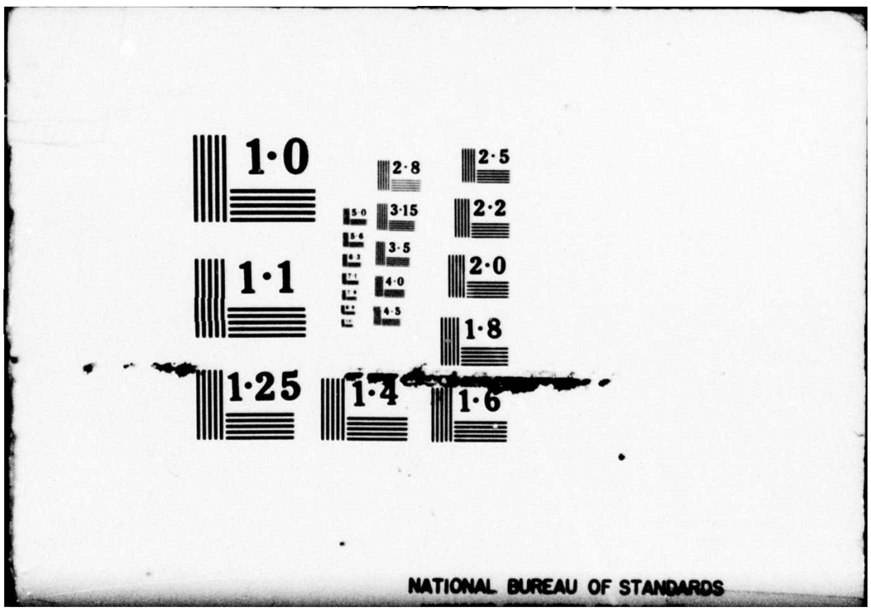
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TERMINAL RADAR INTERFERENCE CRITERIA STUDY

John Kenton

JUNE 1978

FINAL REPORT

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16. Abstract

Tests were undertaken to investigate the relationship between pulsed-type interference and the air traffic controller working in the terminal area. This was done by recording a series of pulsed-type interference cases and combining them with simulated analog radar targets to form a set of scenarios for display to a group of Federal Aviation Administration (FAA) controllers. Several operational responses were used as performance measures to investigate interference criteria. The interference cases were then quantified and ordered based on two indexing schemes. Tests based on the indices and the performance measures revealed that correlations exist between the operational responses and the interference cases.

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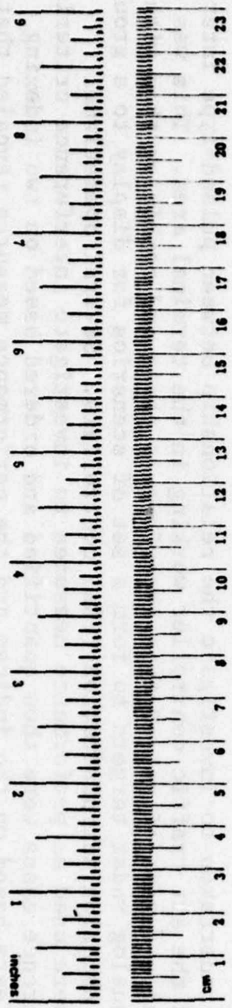
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

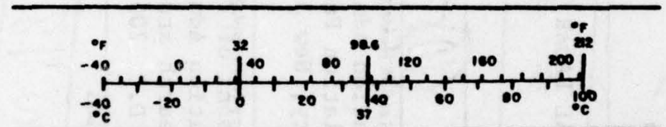
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



PREFACE

Acknowledgement is made to the following NAFEC personnel for their contributions to this project.

Dr. Helen Hamilton of the Human Engineering Branch contributed assistance and comments in the preparation of the controller testing phase.

Mr. Donald Bottomley of the Systems Test Branch added his invaluable inputs on controller operations as well as operating as project controller.

Mr. Edward Hartz of the Surveillance Systems Branch gave his inestimable aid in the preparation, testing, and analysis of results of this project.

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INTRODUCTION

PURPOSE.

This project is intended to aid in the development of threshold criteria for S-band interference in a terminal area. It is the result of an effort to formulate a first-order estimate of a threshold for the terminal area.

BACKGROUND.

Due to increased frequency crowding in recent years, large users of radio-frequency (RF) transmission devices have had to evaluate how well their systems can operate under electromagnetic interference. This represents a problem of particular concern to the Federal Aviation Administration (FAA) due to its use of surveillance systems spanning a wide range of sophistication. Although increased automation is the trend in air traffic control, it is expected that the use of "raw" radar returns will remain a tool in terminal areas.

DISCUSSION

GENERAL.

In the case at hand, a two-fold question is posed: (1) by what criteria can a display's degradation be gauged, and (2) how much interference can be present without impairing the usefulness of the radar display to the air traffic controller?

Although the subject of display degradation has been extensively treated in other publications, most of these investigations have been premised on limiting the constraints of the controller's function. Normally oriented towards the military requirement of "pop-up" targets, these studies will no doubt be of value in subsequent refinement of the current endeavor (one effort of particular interest in this regard is contained in reference 1). Since a formalistic approach (reference 2) to display degradation, which accounts for the differences between the military and civilian control operations, would have gone beyond the scope of this effort, a somewhat simpler method has been used. The approach is essentially based on "typical" FAA control operations under a fixed environment. General considerations on the subject of environment (i.e., displays, traffic patterns, etc.) will be dealt with later in this report. First, the mechanism for quantifying interference in such a way as to be amenable to electromagnetic compatibility analysis (EMC) will be presented. To this end, several prior efforts become particularly significant.

The first of these efforts was conducted by C. L. Hudson at the Rome Air Development Center (reference 3). His aim was to determine the degradation in search radar operator detection times when the interference caused by simulated multiple radars was displayed. A five level classification system of interference conditions used by the United States Air Force (USAF)

(reference 4) formed the basis of the testing. Since one condition or level could very easily be classified as another, a consensus of several operators' classifications of the levels was used to eliminate possibly ambiguous conditions. The five interference levels were then divided into pattern types based on whether they were dots, spirals to dots, or spirals and cross hatch.

It was found from this study that detection times increased with increasing levels as well as with the different types of interference.

A more precise method for identifying the various interference levels was developed by L. Katz in a 1965 Electromagnetic Compatibility Analysis Center (ECAC) effort (reference 5). By relating the intensity of the scope, in the photometric sense of the word, to the number of pulses above the minimum detectable signal of the display, and using the assumption of a linear receiver, the following expression was derived:

$$N = \sum Q_i \, (P_i - P_{mds}) \times 10^{-4}$$

Where: Q_i = number of pulses/scan at power level Pi
P_i = power level category of interfering pulse signals in decibels above one milliwatt (dBm).
P_{mds} = single pulse sensitivity of the Plan Position Indicator (PPI)
N = scope interference level index where
$P_i - P_{mds}$ has a maximum value of the system's dynamic range.

The mean and standard deviation of N numbers derived by Katz for the five interference levels are listed below:

Level	Mean	Standard Deviation
I	2.0	0.5
II	7.8	1.1
III	10.8	2.8
IV	17.8	6.9
V	32.2	9.5

The usefulness of the index number, insofar as interference prediction is concerned, was demonstrated by Maiuzzo in a 1972 ECAC report for the FAA (reference 6). In this report several algorithms were generated by modifying the familiar interference to noise ratio equation to account for the cumulative distribution of antenna gains. One of the algorithms, referred to as the "less stringent interference criteria" and its interpretation, is reprinted here as a point of reference.

$$\frac{I_i}{R'_{sj}}(0.95,\ 0.95) = P_{ti} + G_m\,(0.95) - L_P\,(0.95) - OFR_{ij} - R'_{sj} \leq 0\text{db}$$

Where:

$\frac{I_i}{R'_{sj}}$ (p, q,) = the ratio of peak pulse interference power from the ith radar received by the jth radar to the single-pulse sensitivity of the jth radar, which is not exceeded over p of the cumulative antenna pattern for at least q of hourly median path losses.

P_{ti} = the peak transmitter power of the ith radar.

G_m (0.95) = that level on the mutual antenna gain cumulative distribution which is not exceeded with a probability of 0.95, relative to the mutual gain of two isotropic antennas in free space.

L_p (0.95) = that hourly median path loss exceeded 95 percent of the time.

OFR_{ij} = the off-frequency rejection between the ith transmitter and the jth receiver.

R'_{sj} = the sensitivity of the jth receiver to a single uncorrelated pulse.

Based on this algorithm, it was predicted that interfering pulses would be "sprinkled" on the display via backlobe-to-backlobe antenna coupling. A more stringent criteria, however, led to prediction of a wedge of interference on most antenna rotations through mainbeam-to-sidelobe antenna coupling.

Although the Katz model did not explicitly account for pattern types, it was deemed to be heuristically correct for this investigation. To determine what, if any, relationships exist between interference and the tolerance of air traffic controllers, certain performance indicators had to be isolated. In so doing, it was recognized that the operational functions of the FAA controller are strongly intertwined with procedures. It was decided, therefore, that operational decisions on target visibility, usefulness of display, and acceptance of hand-offs under interference conditions would be used as indicators of controller tolerance to interference. It should be noted that visibility based on a four level rating scale constitutes one of several criteria in flight checking a radar site (reference 7). In addition to these indicators, a fourth measure, the controller's own assessment of how long he would tolerate the interference, was included.

Originally, the detection time of target drops and the tracking accuracy were to be incorporated in this experiment. These two measures had to be eliminated, however, due to hardware limitations.

In order to establish a "typical" environment in which the FAA air traffic controller works, certain ground rules had to be defined. The controllers would be required to work in a situation that would reflect a small terminal area without digitizers, video enhancers, or beacon reinforcement. Video maps and markers would also be excluded.

The work environment would also be in a low lighting, reduced noise area while the displays used would be representative of those currently available in the FAA inventory.

In assessing these latter requirements, it was elected to use several Automated Radar Terminal System (ARTS III) displays in the Terminal Automation Test Facility (TATF) at the National Aviation Facilities Experimental Center (NAFEC). In addition to providing the requisite environment, an internal communications system was available which would more realistically simulate a "handoff" operation.

TEST APPROACH.

In order to provide a reproducible interference situation for controller evaluation, a set of live interference cases between two terminal radars at NAFEC were video taped. A set of target scenarios were then combined with the interference cases onto a second set of video tapes using a computer driven Radar Beacon Simulator (RBS). The resulting video tapes were then displayed to a group of 11 FAA controllers who had had several years experience in working "raw" radar.

During the testing, handoffs of "strong" and "weak" targets to each controller were effected. Each target was rated for 12 scans and each controller's response to various aspects of the interference recorded. The response measures employed are covered in more detail under Controller Testing.

The interference tapes were then digitized using a modified multilevel quantizer (MLQ) to determine the interference index number "N" of each case. A comparison between controller ratings and responses was made to determine their correlation.

TEST SPECIFICS.

INTERFERENCE GENERATION. The interference cases used in this effort were generated using the ASR-5 and ASR-7 radars at NAFEC as the victim and interferer respectively. The two radars, situated approximately 6,900 feet from each other, had a vertical angular separation between antennas of 0.07°, and tilts of 2-1/2° each. Due to their relative positioning, there was almost total antenna coupling between the two radars. Through the mechanism of retuning the ASR-5 to 2735 megahertz (MHz), which was the transmit frequency of the ASR-7, two effects were accomplished. The first was that interference would cover all of the affected radar's display, and secondly, minimization of the effects of the off-frequency correction factor.

After retuning the ASR-5, it was adjusted to receive only. By just receiving the transmissions of the interferer, work was focused on the normal video of the radar. This mode of operation simulated the situation of gated moving target indicator (MTI) since no ground clutter appeared.

Without the victim radar's transmissions, the Automatic Frequency Control (AFC) was disabled and turned off. This meant that the stalo had to be kept 30 MHz, the radar's intermediate frequency (IF), above the 2735 MHz of the interferer by other means. This was accomplished by aligning the radar for 2735 MHz and injecting a pulsed 2765 MHz signal into the waveguide. A variable RF attenuator was then installed between the circulator and the "X" band filter, i.e., before the parametric amplifier of the victim radar. This was done to control the "amount" or intensity of the interference that would appear on a PPI. Since the bandwidths of the ASR-7 and ASR-5 were the same, the bandwidth correction factor was considered to be negligible.

To provide a fairly wide range of antenna coupling, as it would appear on the display, four attenuation settings were selected. The values settled upon ranged from 12 dB to 48 dB in 12 dB increments.

Since the nominal rotation rates of the victim and interfering radars were the same, "wedges" of interference appeared in the same general area from scan to scan. This was a point of tradeoff between the "walking wedge" phenomena, where the interference occurs in different sectors of the display from scan to scan, and the need to have simulated targets traverse areas of fairly constant interference during controller testing.

The nominal and measured rotation rates of the two radars as well as other pertinent operating parameters of the two radars are listed in table 1.

Selection of the pulse repetition frequencies (prfs) to be used by the interfering radar was based on the assumption that a fairly random distribution on the victim's display would reduce, as much as possible, any visual uniqueness of the interference, i.e., strobing and solid spirals.

Subsequent to screening the possible interfering prfs, three were selected. The three were 931, 1150, and the six pulse stagger of the ASR-7 with an average value of 1013. The patterns that were generated when the victim radar operated at 1030 pulses per second (pps) are shown in the computer generated plots in figures 1, 2, and 3. These plots, of course, do not reflect the effects of antenna coupling.

Taping of the interference cases was performed on 2 successive days. On each day, the sequence of the 12 interference cases, i.e., 3 prfs x 4 attenuations, was randomized and recorded on three video tapes using an FR-950 video recorder. Each case was approximately 5 minutes in length with a 30-second interval between cases. The two sequences, hereafter referred to as 1 and 2, of interference cases and their times are listed in table 2.

Along with the video, the azimuth angles of both the interferer and victim radars were also recorded. A plot of the times, and consequently the angular differences between the victim's and interferer's north marks, is shown in figure 4. The fact that an overall nonconstant drift in the relative positions of the two antennas was present typifies their independence of one another.

In order to provide reference back to the radar when the interference indices had to be determined, a set of test signals was generated on each tape using the signal generator mentioned previously. At the beginning of each sequence, the test signals were recorded at three levels. The values of these signals, after compensating for all insertion losses, are shown in table 2.

TABLE 1

OPERATIONAL PARAMETERS

	ASR-5	ASR-7
Transmitter System		**Transmitter System**
Magnetron	---	5586 (tuneable)
Frequency	---	2735 MHz
Pulse Width	---	.833 μs
Power Out	---	.4-.45 mW
PRF	1030	6 pulse stagger 1098 1029 1149.5 931 1176 699
Receiver System		**Receiver System**
Frequency	2735 MHz	---
Sensitivity		---
Normal	-108 dBm (measured)	---
MTI	Off	---
STC	Off	
Antenna		**Antenna**
Gain	34 dB$_i$	34 dB
Polarization	vertical	vertical
Nominal scan Rate	12.75 rpm nom.	12.75 rpm
Average scan Rate	12.81 rpm	12.80 rpm
Beamwidth	1.50°	1.50°
Tilt	2.50°	2.50°

On the first tape of each sequence a two minute period was recorded with the radar shutter closed. This prevented most of the interference from entering the receiver while preserving the receiver noise. This 2-minute period was

TABLE 2
TAPE TEST SEQUENCE

SEQUENCE 1	Time	PRF	Attenuation	Test Signal	*Equivalent Signal
Tape 1	00:00-01:00	931	0	-62	-97
	01:15-02:15	931	0	-56	-91
	02:30-03:30	931	0	-48	-83
shutters closed	03:45-05:45	---	-	---	---
	06:15-11:15	931	-12	-48	-95
	11:45-16:45	1150	-24	-48	-107
	17:15-22:15	stagger	-48	-48	-
	22:45-27:45	931	-36	-48	-
Tape 2	00:00-01:00	931	0	-48	-83
	01:15-06:15	stagger	-12	-48	-95
	06:45-11:45	stagger	-24	-48	-107
	12:15-17:15	931	-24	-48	-107
	17:45-22:45	1150	-12	-48	-95
	23:15-28:15	stagger	-36	-48	-
Tape 3	00:00-01:00	931	0	-48	-83
	01:15-06:15	931	-48	-48	-
	06:45-11:45	1150	-36	-48	-
	12:15-17:15	1150	-48	-48	-
SEQUENCE 2					
Tape 4	00:00-01:00	931	0	-60	-95
	01:15-02:15	931	0	-54	-89
	02:30-03:30	931	0	-45	-80
shutters closed	03:45-05:45	-	---	---	---
	06:15-11:15	stagger	-48	-45	-
	11:45-16:45	stagger	-12	-45	-92
	17:15-22:15	931	-24	-45	-104
	22:45-27:45	931	-12	-45	-92
Tape 5	00:00-01:00	931	0	-45	-80
	01:15-06:15	stagger	-24	-45	-104
	06:45-11:45	1150	-12	-45	-92
	12:15-17:15	stagger	-36	-45	-
	17:45-22:45	1150	-36	-45	-
	23:15-28:15	1150	-24	-45	-104
Tape 6	00:00-01:00	931	-45	0	-80
	01:15-06:15	931	-45	-36	-
	06:45-11:45	1150	-45	-48	-
	12:15-17:15	931	-45	-48	-

*Equivalent signal after compensating for insertion loss of -35 dB.

included to provide a means for rating targets without interference. Subsequent to opening the shutter, the signal generator was set at receiver saturation, approximately -83 dBm. This signal, in combination with the attenuator, resulted in the set of "equivalent test signals" in table 2. The total number of test signals thus produced provided power reference levels covering the 25-dB dynamic range of the receiver.

TARGET SCENARIOS. Prior to preparing the target scenarios, a review of each of the recorded interference cases was made. After assuring the general locale of the interference on a PPI, a set of scenarios was prepared using a Radar Beacon Simulator (RBS). This device operates by adding video targets to the input radar video, in this case the interference tapes. The output was then recorded on a second FR-950 video tape recorder. In addition to being able to produce as many as 32 separately-controllable targets, each with a sinx/x nonfluctuating amplitude distribution, the RBS also produced beacon codes for each target. These codes were recorded on a second track of the video tapes with the intention of providing a means for detection time measurements via trackball entries. Software limitations prohibited such measurements, although the codes provided a means for effecting handoffs, as will be discussed under Controller Testing.

Each sequence was begun by recording a ring of 32 targets at 25 nautical miles (nmi). Peak voltage of these targets was established at 1/2-volt signal plus noise-to-noise ratio to compensate for a 1/4-volt baseline clipping action by the RBS. These targets were recorded at the beginning of the shutter closure time to provide a reference by which to adjust the test displays.

One minute after the occurrence of the ring targets, but still during the shutter time, two targets were generated in the northwest quadrant and proceeded southeast from 27 to 23 nmi at 200 knots (kn). These targets were established at a strength sufficient to produce consistent ratings of 3 for 1 and between 1 and 2 for the other based on the rating scale shown in table 3. The ratings for these targets were determined by having three of the project personnel rate the range of target strengths possible with the RBS. Although this procedure was somewhat coarse, it was sufficient to isolate target strengths that would elicit "strong" and "barely usable" ratings from the test controllers. It was also reasoned that, since rating degradation would be based on the rating differences of targets "in" and "out of" interference for each controller, the approach would be adequate.

Subsequent to the shutter closure interval, the relevant scenario for each interference case was recorded. Each scenario was comprised of 10 targets of which nine were equal in strength to the aforementioned "strong" target. The 10th target was a barely usable one. One of the strong targets and the barely usable one were designated as the ones with which the controllers would work, i.e., track and rate. In the cases where the interference did not cover the display, the targets began at the fringe and proceeded into the cluttered area. Other pertinent aspects of the two primary targets were a constant speed of 200 knots and paths maintained in the annular region of 23 to 27 nmi. The constant range was maintained to minimize size variations with distance.

The resultant interference-scenario combinations are demonstrated in figures 5 through 13 for nine of the 12 cases.

Typical of the scenarios employed in the different interference cases are those recorded by time lapse photography in figures 14 and 15. In these, the beacon video is shown for 30 and 45 scans respectively. In most of the scenarios, the two targets of concern were begun in the northeast quadrant and headed in a southwesterly direction. In each case, other targets were in the same general area of the two rating targets often crossing tracks, as exemplified by the target tracks in the northeast quadrant of figure 15.

TABLE 3

CONTROLLER RATING SCALE

QUALITY	TARGET DESCRIPTION	EXPLANATION
3	Usable	Visible, with definite trail
2	Usable	Visible, without definite trail
1	Weak	Target barely visible, possible miss, unusable
0	Miss	No visible target

CONTROLLER TESTING. Controller testing was conducted using two of the ARTS III displays located in the Terminal Automation Test Facility at NAFEC (figures 16 and 17). A third display, located out of viewing range of the first two, was used by a project controller to provide "handoff" information to the test subjects. Digitized targets with unique beacon codes were shown on this display thereby providing precise information from a second, "imaginary sector" to the test subjects.

The pool of subjects used in this effort was comprised of 11 FAA air traffic controllers, none of whom had any other contact with the project. The total number of years each individual had been a controller ranged from 19 to 30 years with an average of 22.6 years. The total time each had operated with strictly "raw" radar or with minimal beacon reinforcement spread from 5 to 15 years with an average of 8.1 years experience.

It was originally intended to have each controller view both tape sequences, i.e., replicate the prf x attenuation matrix on both displays. This requirement, however, had to be relaxed with the resulting controller test matrix shown in table 4.

Two controllers were used in each test period. The session would begin with the controllers being briefed on the test procedures. They were then given a preliminary run to complete their familiarization. At the beginning of the actual test the displays were set to 35 nmi and all video controls turned down. Both controllers were then instructed to adjust the sweep intensity until it was just visible, and to set the video gain at the point where the ring targets, generated during the shutter closure time, were also just visible. It was felt that with the ring targets set at the nominal noise value of the radar video, and in conjunction with their sinx/x distributions, a close approximation to the single pulse sensitivity of each controller could be obtained. In effect, the requisite noise breakthrough could be approached. Display controls were not changed until after the sequence had been completed.

Throughout every test session the output of the final mixer, prior to the cathode ray tube (CRT) amplifier, was monitored to assure consistent display operation.

Since the displays were to be operated in the same manner as those used in the field, the CRT protective filters were retained. These filters were orange-yellow in color and had a measured transmittance of 66 percent for display 1 and 53 percent for display 2.

TABLE 4

CONTROLLER TEST TABLE

	Tape Sequence 1		Tape Sequence 2	
ATC Number	Display 1	Display 2	Display 1	Display 2
1	x			x
2		x	x	
3	x			x
4		x	x	
5		x	x	
6	x			x
7		x	x	
8	x			x
9		x	x	
10	x			x
11		x		x

Upon appearance of the "baseline" targets, each controller reported his ratings for both targets on a scan-by-scan basis for five scans. These ratings were recorded by a scorer seated beside the controller. The step-by-step sequence followed during each scenario was as follows:

1. The project controller vectored both subjects to the two targets and identified them as targets "A" and "B." The designations A and B were assigned randomly to the strong and weak targets.

2. Each subject rated both A and B on each scan for 12 successive scans, reporting on them in the A and B order.

3. Each subject was vectored to a third strong target, in an area of the display devoid of other targets, by the project controller. At this point each responded as to whether he would accept the handoff under that particular interference condition. This question was prefaced by stating that the controller had "the option of rejecting the handoff under the prevailing interference condition." By keeping the area of the handoff clear of other targets, it was believed that a rejection would be in terms of the intangibles of controller operations rather than the simplistic concept of possible confusion with another target. Among the intangibles would be whether the controller could perform step 4.

4. The project controller then directed the subjects to reidentify target A or B. This output measure was of limited use due to certain hardware limitations. It was retained in the test, however, because of its relationship to step 3 as a simulated workload.

5. The controllers were told that four targets were inbound along the cardinal radials, i.e., North, South, East, and West, and that one would "drop out." They were to identify which one. As in step 4, this measure suffered from hardware limitations part way through the testing. Its retention was based on maintaining the continuity of the testing, as well as providing another facet of a simulated workload.

6. The subjects were then queried as to how long they would tolerate the interference condition during a watch without reducing their regular workload. Period intervals were confined to 0, 25, 50, 75, and 100 percent of the watch.

7. A second question posed was the controller's individual evaluation of the overall interference condition. A selection of one of three responses was permitted. These responses were:

(A) Could use the display without any difficulty.

(B) Could use the display under reduced workload.

(C) Display was completely unacceptable.

INTERFERENCE INDICES AND MEASUREMENTS

GENERAL.

To determine the N values of the interference cases a "power bin" method, similar but with slight alteration to that employed by Katz, was used.

First, the linear region of the victim receiver's response curve was divided into four bins of 5 dBm each. This covered the range from -98 dBm to -78 dBm, -83 dBm being the point of receiver saturation. Next, -96 dBm was subtracted from the midpoint of each power bin to provide the $P_i - P_{mds}$ terms in the Katz expression:

$$N = \Sigma Q_i \ (P_i - P_{mds}) \times 10^{-4}$$

The -96 dBm represented the single pulse sensitivity, which is nominally 12 dB above the receiver's minimum discernible signal. The resulting four values were then attached to each interference pulse that occurred within each bin. The N value on a scan-by-scan basis was then calculated by summing the products of the number of pulses in each bin and the power value of the respective bins. The average value for between 30 and 33 scans was then used to classify the interference.

In order to derive the number of pulses in each bin, a portable multilevel quantizer (PMLQ) was modified to operate in a thresholding mode. The PMLQ itself consists of a series of 16 adjustable comparators driven by a common input amplifier. Each comparator is set to trigger at increasing video levels. The highest ordered comparator is then sensed, digitized, and in normal operation fed to a computer. This output is updated at preselectable 1/16, 1/8, 1/4, or 1/2 nmi increments.

In this effort, the decoding matrix of the MLQ and the computer were bypassed with only the "front end" of the MLQ being used. Four of the comparators were set to threshold at the lower levels of the respective power bins. These levels were obtained by applying a linear regression to the receiver response curve shown in figure 18. The other 12 comparators were removed from operation by grounding their inputs. The outputs of the comparator circuits, figure 19, were tapped and fed to a fabricated gating circuit. This gating circuit was used to limit the counting of interference pulses to those within 35 nmi, the display range used during testing. It also provided a 0.25 microsecond (μs) rise-time isolation between successive bins, i.e., an interfering pulse that passed through a power bin to a higher level in less than a quarter microsecond would not be counted as part of the transitioned bin. Two outputs of the gating circuit were fed into pulse generators, acting as Schmidt triggers, to drive two counters. These in turn totalized the counts between azimuth pulses (ARPs). The readings of the counters were then input to a digital recorder, producing a hardcopy output of the number of pulses in two of the four power bins. This resulted in 30 to 33 scans being recorded out of the approximately 67 scans possible, every other scan being dead time for the counters used. The numbers

for the other two power bins were obtained in the same fashion by rerunning the tapes and switching to the second two outputs of the gating circuit.

The resulting N numbers, broken down into sequence, prf, and attenuation values, are shown in table 5.

To explore a possible relationship between controller responses and the amount of time a display was being "painted," a modified index number "M" was generated. This number is expressed as:

$$M = \sum t_i (P_i - P_{mds}) \times 10^{-4}$$

Where M = modified index number

t_i = total time that power bin "i" was occupied by the peaks of interfering pulses. Time is in increments of 1/16 nmi (0.77 μs).

The reason for this measure generated from the concern that pulse stretching during receiver saturation might predominate in cases where attenuation values were low.

To derive the M number, the same procedure utilized in determining the N values was used, except that the 1/16-nmi clock of the MLQ gated the gating circuit. Since the nominal pulse width of the interfering pulses and the range clock were very close (0.83 μs versus 0.77 μs) a close approximation of M could be derived. The resulting M values for the respective cases are listed in table 6.

Appendix A contains an example of how the N and M indices were calculated. Included are the measured "Q" and "t" values for each case.

TABLE 5

N NUMBERS

	PRF	Attenuation	N Mean	N Standard Deviation
Tape 1	931	12	9.269	0.120
	1150	24	7.987	0.116
	1013.5	48	4.416	0.117
	931	36	5.062	0.069
Tape 2	1013.5	12	9.414	0.143
	1013.5	24	7.016	0.113
	931	24	6.843	0.098
	1150	12	10.562	0.108
	1013.5	36	4.968	0.086
Tape 3	931	48	4.337	0.110
	1150	36	5.270	0.091
	1150	48	4.406	0.097
Tape 4	1013.5	48	DATA NOT AVAILABLE FROM TAPE	
	1013.5	12	8.106	0.263
	931	24	7.223	0.501
	931	12	9.470	0.090
Tape 5	1013.5	24	5.802	0.090
	1150	12	9.654	0.119
	1013.5	36	3.790	0.088
	1150	36	4.125	0.080
	1150	24	6.774	0.117
Tape 6	931	36	3.756	0.084
	1150	48	3.274	0.079
	931	48	3.176	0.071

TABLE 6

M NUMBERS

	PRF	Attenuation	M Mean	M Standard Deviation
Tape 1	931	12	14.298	0.178
	1150	24	12.350	0.080
	1013.5	48	9.409	0.180
	931	36	9.402	0.131
	1013.5	12	14.122	0.210
Tape 2	1013.5	24	11.427	0.142
	931	24	10.902	0.172
	1150	12	15.516	0.152
	1013.5	36	9.164	0.184
Tape 3	931	48	9.171	0.104
	1150	36	9.995	0.230
	1150	48	9.359	0.117
Tape 4	1013.5	48	10.818	1.304
	1013.5	12	14.185	0.176
	931	24	12.256	0.727
	931	12	13.488	0.169
Tape 5	1013.5	24	11.944	0.134
	1150	12	16.800	0.181
	1013.5	36	10.430	0.204
	1150	36	10.389	0.171
	1150	24	12.913	0.148
Tape 6	931	36	9.855	0.136
	1150	48	9.352	0.117
	931	48	9.354	0.137

RESULTS

An analysis of the results of these tests is premised on answering two questions, which are:

1. Is there sufficient correlation between the interference indices, N or M, to indicate a relationship between interference and the respective performance indicators; i.e., do criteria exist?

2. Which of those cases studied, if any, represents a threshold in terms of the two indices?

The four performance indicator results are presented in this section and are accompanied by the relevant tests of correlation for the two indices and the thresholds where obtained. It should be noted that in the accompanying tables sequence 1 is separated from sequence 2. This is done because of the previously mentioned change in antenna couplings that took place between the two taping sessions. This change in coupling effectively causes the same prf x attenuation condition in both sessions to be different. This, of course, was to be expected, but it also gave rise to another reason for sequence separation, a larger sampling of the possible N and M values. The tables are sometimes presented with the controller test matrix, while prf/attenuation settings are shown in all cases. This is done to facilitate cross-referencing between tests. Where appropriate, the tables are listed in terms of increasing N and M values.

DECREASE IN TARGET RATINGS.

The differences between the ratings of the strong targets, both with and without interference, are presented in table 7. Each entry is the difference registered by each controller. The same arrangement for the weak targets is found in table 8. In both tables the absence of a sign means a decrease in target rating, while a negative sign means an increase in rating over the no interference situation. Difference figures have been recorded to the first decimal place due to the inherent nonparametric nature of target ratings. To clarify this point, the rating method is ordinal and represents a ranking of target visibility only. By taking the difference between each controller's average rating of the target, without interference and with interference, a measure of the decrease in visibility on a per-controller basis is generated. Using this system, each controller acts as his own reference. Since these differences were based on 12 scans, a more exact value other than 0.1 becomes dubious. Averaging of the decrease in ratings is of course limited to the appropriate number of significant figures.

To determine the correlation between the decrease in rating and the two interference indicies, the Spearman rank correlation coefficient, r_s, is used (reference 8). In essence, this coefficient is a measure of association between two variables that are ranked. The coefficient can take on values from 0 to ± 1. A value of ± 1 means perfect correlation, while zero shows no correlation exists. The sign indicates the direction of correlation. The method that is used is to rank both of the variables separately in order of increasing magnitudes.

TABLE 7. TARGET RATING DECREASE (STRONG TARGET)

SEQUENCE I

PRF			931	1150	1013	931	1013	1013	931	1150	1013	931	1150	1150
Attenuation (dB)			12	24	48	36	12	24	24	12	36	48	36	48
ATC No.	Display 1	Display 2												
1	x		0	0	0	0	0	-	0.1	0.1	0	0	0	0
2		x	0	0	0	0	0	0	0	0	0	0	0	0
3	x		0.2	0.8	0.4	0	0.8	1.2	0.8	1.5	0.2	0.8	0.2	0.4
4		x	0.7	0.6	0	0.7	0.2	0.8	0.5	1.6	0.4	0.7	0.3	0.2
5		x	0	0	0	0	0	0	0	0	0	0.1	0	0
6	x		-	0.6	0.4	0.2	0.6	0.7	0.7	0.8	0.4	0	0.2	0
7		x	1.0	0.8	1.0	1.0	0.6	0.7	0.6	1.0	0	0.8	1.0	0
8	x		0.6	0	-.4	0.4	1.4	1.2	1.2	1.6	0.4	1.4	1.6	-.2
9		x	0	-.2	0	0	1.0	0.6	0	1.0	-.1	0	0	0
10	x		0.9	0.1	-.9	1.0	1.0	0	0	0.9	-.2	0.1	0.2	0
11		x	0	0	0	0	0.5	0.2	0	0.2	0	0.4	0.1	0
Average			0.3	0.2	0.0	0.3	0.6	0.5	0.4	0.8	0.1	0.4	0.3	0.0
Reject			x	x		x	x	x	x	x		x	x	

SEQUENCE II

PRF			1013	1013	931	931	1013	1150	1013	1150	1150	931	1150	931
Attenuation (dB)			48	12	24	12	24	12	36	36	24	36	48	48
ATC No.	Display 1	Display 2												
1		x	0	0	0	0	0	0	0	0	0	0	0	0
2	x		0	0.3	0.2	0.9	0	0.2	0	0.8	0	0	0	0
3		x	0.1	1.0	1.3	1.1	1.5	1.4	0.9	0.5	1.1	0.4	0.8	0
4	x		0.3	1.2	3.0	1.5	1.6	1.8	0.9	0.2	1.3	1.3	0.6	0.1
5	x		0	0	0	0	0	0.1	0	0	0	0	0	0
6		x	1.0	1.0	1.0	1.0	0.6	1.0	0.4	0	1.0	2.0	2.0	2.0
7	x		1.0	1.0	1.0	1.7	1.0	2.0	1.0	1.0	1.0	1.3	1.0	1.0
8		x	0	0.2	0	0.1	0.1	0.8	0	0	0	0	0	0
9	x		0.1	0.9	1.0	1.0	0.8	1.0	0.7	0.1	0.1	0.4	0	0
10		x	0	1.0	1.0	1.0	0.2	1.0	0.1	0.8	0	0	0	0
11		x	0.5	0.9	0.4	0.8	0.1	0.2	0	0	0	0	0	0
Average			0.3	0.7	0.8	0.8	0.5	0.9	0.4	0.3	0.4	0.5	0.4	0.3
Reject			x	x	x	x	x	x	x	x	x	x		

NOTE: Rejection at 0.05 Level Based on Binomial Test

TABLE 8. TARGET RATING DECREASE (WEAK TARGET)

SEQUENCE I

PRF			931	1150	1013	931	1013	1013	931	1150	1013	931	1150	1150
Attenuation (dB)			12	24	48	36	12	24	24	12	36	48	36	48
ATC	Display													
No.	1	2												
1	x		0	0.2	-.6	0.6	1.2	-	-	-	0.8	0.8	1.2	0.8
2		x	0	0	-.2	0	1.0	0	0	0.8	0	0	0	0
3	x		0.9	0.9	-	0.4	0.8	0.7	0.8	1.0	0.8	1.0	0.8	1.0
4		x	-.9	1.1	-.3	1.0	1.1	0.9	1.1	1.1	1.2	0.7	0.6	0.2
5		x	0.2	0.4	0.4	0.4	0.4	0.4	0.7	0.7	0.4	0.4	0.4	0.4
6	x		-	0	0	0	0	0	0.4	0.4	0	0	0	-.6
7		x	0	0	0	0.1	0	0	0	0	0	0.1	0	0
8	x		0	0	-.2	0	1.0	0.7	1.0	1.0	0.8	1.0	1.0	0
9		x	0.2	0.2	0	0	1.0	0.3	0	-.1	0.2	0.1	0	0
10	x		0.1	0.1	0.2	0.2	0.3	0.4	0.9	0.3	0.1	0.2	0	0
11		x	0.6	0.4	0.2	0.5	0.8	0.6	0.7	0.1	0.8	1.0	1.2	1.0
Average			0.1	0.3	0.0	0.3	0.7	0.4	0.6	0.5	0.5	0.5	0.5	0.2
Reject			x	x		x	x	x	x	x	x	x	x	x

SEQUENCE II

PRF			1013	1013	931	931	1013	1150	1013	1150	1150	931	1150	931
Attenuation (dB)			48	12	24	12	24	12	36	36	24	36	48	48
ATC	Display													
No.	1	2												
1		x	0	0	0.4	1.0	1.0	1.0	1.0	1.0	0.3	1.0	1.0	0.6
2	x		-.1	0	0	0	0	0	0	0.1	0	0.1	0	-.2
3		x	-.2	0	0.2	-.8	0.1	0.1	-.3	-.3	0	0	0	-.8
4	x		-.1	0	-.9	0.1	0.3	0.5	-.9	-.2	0	0.1	0	-.4
5	x		-.2	0	0	0.2	0	0.6	0.3	0	0.1	-.1	0	-.2
6		x	0	0	0	0	0	0	0	0	0	1.0	1.0	0.8
7	x		0.5	0.5	0.5	1.5	-	1.5	1.3	0.7	-	0.8	0.5	0.6
8		x	-.8	0	0	0	0	0	-.4	0	0	0	0	-.2
9	x		-.1	0	-.1	-.1	-.1	-.2	0	-.2	-.1	0	-.2	-.3
10		x	0.2	0.8	0.3	1.0	0.4	1.2	1.2	0.5	1.1	0.8	0.2	1.0
11		x	1.1	1.2	1.5	1.3	0.3	0.8	0.4	0.2	-.2	0.2	-.8	-.8
Average			0.0	0.2	0.2	0.4	0.2	0.5	0.2	0.2	0.1	0.4	0.2	0.0
Reject					x	x	x	x	x	x		x		

NOTE: Rejection at 0.05 Level Based on Binomial test

In table 9 the interference index N is listed in ascending order and given the appropriate ranking in the N column at the right of the table. The strong target rating decreases are ranked and listed under column A. The same procedure is followed for the weak targets and is found in column B. Where ties occur, the average of the ranks that would have been used is assigned to each of the entries. For instance, a rating decrease of 0.0 is registered for two entries under the strong target. Each is assigned a value of (1+2)/2=1.5 and entered in column A. The next available rank is 3, which is assigned to the rating decrease of 0.1.

Once the rankings have been completed, the differences are found between the N rankings and the corresponding rankings in the A column. The resulting differences are squared and summed as indicated in the d_A^2 column. The same process is employed for the N versus B rankings. Since all operations are common to the N versus A, N versus B, M versus A, and the M versus B rankings, subsequent discussion will be in reference to the N versus A rankings.

The Spearman correlation coefficient is:

$$r_s = \frac{\Sigma x^2 + \Sigma y^2 - \Sigma d^2}{2\sqrt{\Sigma x^2 \; \Sigma y^2}}$$

where:

$$\Sigma x^2 = \frac{n^3 - n}{12}$$

$$\Sigma y^2 = \frac{n^3 - n}{12} - \Sigma \, t_y^3 - t_y$$

The terms used in the above expression are:

n = number of ranks. Note that a lower case n is used to designate the number of ranks, while the upper case N retains its meaning as an interference index.

t_y = number of observations of the dependent variable tied at a given rank.

In the above expressions (reference 8), the sums over x^2 and y^2 represent the contributions to the correlation coefficient due to the ordering of the interference index and decrease in target ratings respectively. Also, the summation over $(t^3-t)/12$ represents a correction factor for tied ranks. This correction is implemented by noting that in column A, table 9, there are two observations listed at 0.0, five at 0.3, five at 0.4, three at 0.5, and three at 0.8 therefore:

$$\frac{\Sigma t_y^3 - t_y}{12} = \frac{(2^3-2)+(5^3-5)+(5^3-5)+(3^3-3)+(3^3-3)}{12}$$

$$= \frac{294}{12} = 24.50$$

TABLE 9. SUMMARY OF TARGET RATING DECREASE DATA VERSUS N

N#	TARGET A*	TARGET B*	Ranks of Previous Columns N	Ranks of Previous Columns A*	Ranks of Previous Columns B*	d_A^2	d_B^2	Conditions Rejected Based on Target Rating Decrease A*	Conditions Rejected Based on Target Rating Decrease B*
3.176	.3	.0	1	7	1.5	36	0.25		
3.274	.4	.2	2	12	8	100	36		
3.756	.5	.4	3	16	15	169	144	x	x
3.790	.4	.2	4	12	8	64	16	x	x
4.125	.3	.2	5	7	8	4	9	x	x
4.337	.4	.5	6	12	19	36	169	x	x
4.406	.0	.2	7	1.5	8	30.25	1		x
4.416	.0	.0	8	1.5	1.5	42.25	42.25		
4.968	.1	.5	9	3	19	36	100		x
5.062	.3	.3	10	7	12.5	9	6.25	x	x
5.270	.3	.5	11	7	19	16	64	x	x
5.802	.5	.2	12	16	8	16	16	x	x
6.774	.4	.1	13	12	3.5	1	90.25	x	
6.843	.4	.6	14	12	22	4	64	x	x
7.016	.5	.4	15	16	15	1	0	x	x
7.223	.8	.2	16	21	8	25	64	x	x
7.987	.2	.3	17	4	12.5	169	20.25	x	x
8.106	.7	.2	18	19	8	1	100	x	
9.269	.3	.1	19	7	3.5	144	240.25	x	x
9.414	.6	.7	20	18	23	4	9	x	x
9.470	.8	.4	21	21	15	0	36	x	x
9.664	.9	.5	22	23	19	1	9	x	x
10.562	.8	.5	23	21	19	4	16	x	x

Correlation Coefficients $\Sigma d_A^2 = 912.50$ $\Sigma d_B^2 = 1252.50$

$r_{SA} = 0.54$ $r_{SB} = 0.37$

*A - Strong

*B - Weak

is applied to the $(n^3-n)/12$ term; the same term which gives the summation over x^2, with the resulting values:

$$\Sigma x^2 = \frac{23^3-23}{12} = 1012$$

$$\Sigma y^2 = \frac{23^3-23}{12} - 24.50 = 1012-24.50 = 987.50$$

Inserting these values along with the Σd_A^2 into the r_s expression gives:

$$r_{sa} = \frac{1012+987.50-912.50}{2\left[(1012)(987.5)\right]^{1/2}} = 0.54$$

This value is listed in table 9, and is designated as r_{SA}. The correlation coefficient for the decrease in ratings for weak targets is determined to be:

$$r_{sb} = \frac{1012+970.50-1252.50}{2\left[(1012)\ (970.50)\right]^{1/2}} = 0.37$$

This value is also listed in table 9. Table 10 is constructed in the same fashion as table 9, but it is based on the ranking of the index M. The correlation coefficients for the strong and weak targets, r_{SA} and r_{SB}, are determined from the resulting expression:

$$r_{sa} = \frac{1150+1118-861}{2\left[(1150)(1118)\right]^{1/2}} = 0.62$$

$$r_{sb} = \frac{1150+1107-1996}{2\left[(1150)(1107)\right]^{1/2}} = 0.12$$

To determine whether the above correlations are significant and not a result of random chance, the hypothesis is formed that the correlations are actually zero. The test shall be such that observing correlations as great as those listed previously as a result of chance is 5 percent. If such a value is observed, it is declared not to be a result of random variation, but a sample with a correlation distinct from zero. More succinctly, a test will be performed at the 0.05 level that: $H_o : r_s = 0$ with the alternate hypothesis $H_1 : r_s > 0$. This constitutes a one tailed test of significance at the 0.05 level. Due to its directional nature, the test is performed by using the statistic (reference 8).

$$t = r_s\sqrt{\frac{n-2}{1-r_s^2}}$$

TABLE 10. SUMMARY OF TARGET RATING DECREASE DATA VERSUS M

	TARGET		Ranks of Previous Columns					Conditions Rejected Based on Target Rating Decrease	
M#	A*	B*	M	A*	B*	d_A^2	d_B^2	A*	B*
9.164	.1	.5	1	3	20	4	361		x
9.171	.4	.5	2	13	20	121	324	x	x
9.352	.4	.2	3	13	9	100	36		
9.354	.3	.0	4	7.5	2	12.25	4		
9.359	.0	.2	5	1.5	9	12.25	16		x
9.402	.3	.3	6	7.5	13.5	12.25	56.25	x	x
9.409	.0	.0	7	1.5	2	30.25	25		
9.855	.5	.4	8	17	16	81	64	x	x
9.995	.3	.5	9	7.5	20	2.25	121	x	x
10.389	.3	.2	10	7.5	9	6.25	1	x	x
10.430	.4	.2	11	13	9	4	4	x	x
10.818	.3	.0	12	7.5	2	20.25	100	x	
10.902	.4	.6	13	13	23	0	100	x	x
11.427	.5	.4	14	17	16	9	4	x	x
11.944	.5	.2	15	17	9	4	36	x	x
12.256	.8	.2	16	22	9	36	49	x	x
12.350	.2	.3	17	4	13.5	169	12.25	x	x
12.913	.4	.1	18	13	4.5	25	182.25	x	
13.488	.8	.4	19	22	16	9	9	x	x
14.122	.6	.7	20	19	24	1	16	x	x
14.185	.7	.2	21	20	9	1	144	x	
14.298	.3	.1	22	7.5	4.5	210.25	306.25	x	x
15.516	.8	.5	23	22	20	1	9	x	x
16.800	.9	.5	24	24	20	0	16	x	x

Correlation Coefficients $\Sigma d_A^2 = 861.00$ $\Sigma d_B^2 = 1996.00$

$r_{SA} = 0.62$ $r_{SB} = 0.12$

*A - Strong
*B - Weak

This statistic has a Student's t distribution with n-2 degrees of freedom. Designating the statistics by subscripting the interference index, N or M, and the A or B designators for the strong and weak targets, the resulting t values are:

$$t_{NA} = 0.54\sqrt{\frac{23-2}{1-(0.54)^2}} = 2.94$$

$$t_{NB} = 0.37\sqrt{\frac{23-2}{1-(0.37)^2}} = 1.83$$

$$t_{MA} = 0.62\sqrt{\frac{24-2}{1-(0.62)^2}} = 3.71$$

$$t_{MB} = 0.12\sqrt{\frac{24-2}{1-(0.12)^2}} = 0.57$$

The 0.05 one-tailed critical values of the Student's t are: 1.271 for 21 degrees of freedom and 1.721 for 22 degrees of freedom (reference 8). The resulting statistics reveal that all except the correlation between the decrease in weak target ratings versus M are significant. They are sufficiently greater than zero to constitute rare events. Therefore, a correlation exists between the decrease in target ratings for strong and weak targets and the N index. A correlation also exists between the decrease in strong target ratings and the index M. The correlation between the decrease in weak target ratings and M may have been observed as a result of chance or there may, in fact, be an undetected correlation.

From the above discussion, it appears that the N classification is preferable to the M index in that it correlates with both the strong and weak targets, while the M index fails to correlate with the decrease in ratings for weak targets. Although the correlation with strong target decreases is slightly more significant using the M index (a t value of 3.71 compared with that of 2.94 for the N index), the confirmed correlation between N and weak target decreases would be preferable to the uncertain situation of the M correlation.

It is now possible to assess the effects of the individual interference cases upon the decrease in ratings. This is accomplished by comparing the nature of the change in ratings with and without interference. It rests on the assumption that the proportion of controllers who registered a decrease in rating without interference should have remained the same when interference was present. If there was a marked increase in the number of controllers who indicated a decreased rating, then it can be assumed that the interference had a detrimental effect. This test is implemented by noting the number of controllers who indicated any decrease in ratings of the strong and weak baseline targets. This is summarized as follows for both sequences with the strong and weak targets.

	Sequence 1	Sequence 2
Strong target:	1 decrease, 10 no change	0 decrease, 11 no change
Weak target:	1 decrease, 10 no change	2 decrease, 9 no change

Before proceeding, an important aspect of the targets should be noted. The targets, as stated earlier, were nonfluctuating; therefore, one would expect that no change in ratings would be the common result. In fact this was the case as indicated in the table. By pooling the results, it is noted that there were four decreases out of 44 observations. This constitutes an estimated population proportion of 0.09. The 95-percent confidence limits for this estimate are found in confidence belt charts contained in reference 9. In this case, the confidence limits for the population proportion vary from 0.0 to 0.23. By assuming a conservative proportion equal to 0.2, a set of probabilities can be generated to test the effect of the individual interference cases on target ratings.

If the concern is with the number of unchanged ratings under each condition, where <u>increases in ratings are considered as equivalent to no change</u>, the probability of getting x or fewer no changes in rating can be found through the binomial expansion (reference 8):

$$P\text{ (number of no changes } \leq x) = \sum_{i=0}^{x} \frac{N!}{i!\,(N-i)!} P^{i} Q^{n-i}$$

where: P = expected proportion of no changes = 0.8.
Q = 1-P = expected proportion of decreases = 0.2
N = number of controllers

Evaluating the summation, the probability of observing x or fewer no changes for N=10 and N=11 is:

	N = 11	N = 10
$P(x \leq 0)$	~ 0	~ 0
$P(x \leq 1)$	~ 0	~ 0
$P(x \leq 2)$	~ 0	~ 0
$P(x \leq 3)$	~ 0	= 0.001
$P(x \leq 4)$	= 0.002	= 0.006
$P(x \leq 5)$	= 0.012	= 0.033
$P(x \leq 6)$	= 0.50	= 0.121

If the level of rejection is set at the 0.05 level, then when there are six or fewer no changes and the total number of responses per case equals 11, the hypothesis that no effect was observed is rejected. When the number of responses per condition equals 10, rejection occurs if the number of no changes is five or less. These tests have been applied and are recorded in tables 7 and 8. An example shown in table 8 illustrates the case generated at a prf of 931 with an attenuation of 12 dB, and recorded in sequence 1. The responses are as follows:

Number of entries = 10
Number of zeros = 4
Number of negative entries (increase in ratings) = 1
Total number of no changes - 4+1 = 5

This condition is rejected since there are only five no changes with 10 entries. The conditions rejected based on the foregoing test are recorded in tables 9 and 10. In both tables the nonrejected conditions for strong targets tend to occur at lower values of each index. However, the occurrence of nonrejected conditions, when weak targets are present, tend to be spread over the ranges of the two indices as would be expected from their lower correlations. In both cases however, only five conditions were not rejected. The lowest level at which rejection occurred was 3.8 for the N index for both strong and weak target decreases. The lowest levels of rejection for the M index were both approximately 9.2.

The effects of fluctuating targets, as they occur in a live environment, may have quite different results from those studied. It would be expected that the population proportion of increases to decreases in ratings would be 0.5. But the proportion of decreases to no changes, which in this test includes increases, would have to be determined.

HANDOFFS.

The controllers' acceptance of handoffs versus the two interference indices are shown in figures 20 and 21. Each point represents the percent of controllers who accepted the handoff under the particular interference condition. Eleven controllers were used in all but one of the cases tested. The one exception was for the case of 931 prf/12 dB, sequence 1, in which 10 subjects were available. Also shown in the figures are the linear regression lines for each index. These were generated based on a least squares fit of the expression:

$$y = a_o + a_1 x$$

with: x = interference index number
y = proportion of controllers accepting handoff.

The expressions used for determining the a_o and a_1 terms are as follows (reference 9):

$$a_1 = \frac{\Sigma xy - \frac{\Sigma x \Sigma y}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

$$a_o = \frac{\Sigma y}{n} - a_1 \frac{\Sigma x}{n}$$

The intermediate calculations for determining these terms are given in table 11. Also shown are the correlation coefficients r for the N and M indices. These terms, just as with the Spearman rank coefficient, provide a measure of

TABLE 11. SUMMARY OF PERCENT HANDOFF DATA VERSUS N AND M

N#	Proportion Who Took Handoff	Cases Rejected	M#	Proportion Who Took Handoff	Cases Rejected
3.176	.82		9.164	.64	
3.274	.82		9.171	.82	
3.756	.73		9.352	.82	
3.790	.55		9.354	.82	
4.125	.64		9.359	.82	
4.337	.82		9.402	.82	
4.406	.82		9.409	.91	Reference
4.416	.91	Reference	9.855	.73	
4.968	.64		9.995	.55	
5.062	.82		10.389	.64	
5.270	.55		10.430	.55	
5.802	.55		10.818	.91	Reference
6.774	.55		10.902	.64	
6.843	.64		11.427	.55	
7.016	.55		11.944	.55	
7.223	.45	x	12.256	.45	x
7.987	.73		12.350	.73	
8.106	.36	x	12.913	.55	
9.269	.90		13.488	.36	x
9.414	.45	x	14.122	.45	x
9.470	.36	x	14.185	.36	x
9.664	.18	x	14.298	.90	
10.562	.45	x	15.516	.45	x
			16.800	.18	x

Intermediate Calculations for Linear Regression

	N	M
n	23	24
Σx	144.710	276.899
Σy	14.29	15.20
Σxy	83.81	168.25
Σx^2	1028.534	3309.884
Σy^2	9.71	10.53
a_o	0.946	1.347
a_1	-0.052	-0.062
r	-0.62	-0.70

Regression Curve

$y = a_o + a_{1x}$

x = index number

y = proportion who accepted handoffs

correlation between the two variables of concern. The coefficients are generated from the expression (reference 10).

$$r = \frac{\Sigma xy - \dfrac{\Sigma x \Sigma y}{n}}{\sqrt{\left[\Sigma x^2 - \dfrac{(\Sigma x)^2}{n}\right] \left[\Sigma y^2 - \dfrac{(\Sigma y)^2}{n}\right]}}$$

From table 11 the expressions for the two indices are:

% Handoffs = 95 - 5N, r = -0.62, n = 23
% Handoffs = 135 - 6N, r = -0.70, n = 24

Note that the proportions have been multiplied by 100 to give expressions in percent.

The negative correlations show that as interference increases, acceptance of handoffs decreases.

To test whether the correlation coefficients are significantly different from zero, the t test used previously is applied for the N index:

$$t = r \frac{\sqrt{n-2}}{\sqrt{1-r^2}} = \frac{-0.62 \sqrt{23-2}}{1-(0.62)^2} = -3.621$$

For the M index:

$$t = \frac{-0.70 \sqrt{24-2}}{1-(0.70)^2} = -4.598$$

Since the direction of concern has been specified, a one-tailed test is used. The level of significance for the two correlations are both in excess of the 0.05 level, i.e., $|-3.621| > 1.721$ for 21 degrees of freedom, and $|-4.589| > 1.717$ for 22 degrees of freedom (reference 8). Therefore, both correlations are significant and not a result of chance. This confirms that a linear relationship exists to the extent of the correlation between willingness to accept handoffs and the interference indices.

The question of handoffs, as it was addressed to the test subjects, limited their responses to the interference condition present. As such, since the question under a no-interference condition had no meaning, absolute baseline data is lacking. Due to this lack of adequate baseline information on the handoff measure and the limited number of test subjects, analysis of this test has to be confined to isolating the more obvious interference cases as undesirable. This is accomplished by hypothesizing that in progressing from one condition to another, the controller is equally as likely to accept a handoff where he formerly rejected one as he is to reject a handoff where he had previously accepted one. In essence, if there is no difference between the two conditions, then the number of controllers who change their minds in one direction will tend to counterbalance those who change the other way. This is essentially a sign test (reference 8) where positive changes are offset by negative changes.

TABLE 12. ACCEPTANCE OF HANDOFFS AND REJECTION TABLE

SEQUENCE I

PRF			931	1150	1013	931	1013	1013	931	1150	1013	931	1150	1150
Attenuation (dB)			12	24	48	36	12	24	24	12	36	48	36	48
ATC	Display													
No.	1	2												
1	x		1	1	1	1	1	1	1	0	1	1	1	1
2		x	1	1	1	1	1	1	1	1	1	1	1	1
3	x		1	1	1	1	1	1	1	1	1	1	1	1
4		x	1	1	1	1	1	1	1	1	1	1	1	1
5		x	1	1	1	1	0	1	1	0	1	1	1	1
6	x		-	0	1	0	0	0	0	0	0	1	0	1
7		x	1	0	1	1	0	0	1	1	1	0	0	1
8	x		1	1	0	1	0	0	0	0	0	0	0	1
9		x	1	1	1	1	0	0	1	0	1	1	1	1
10	x		0	0	1	0	0	0	0	0	0	1	0	0
11		x	1	1	1	1	1	1	0	1	0	1	0	0
Average			.90	.73	*.91	.82	.45	.55	.64	.45	.64	.82	.55	.82
Total Changes/ + Changes							5/0			5/0				
Reject							x			x				

SEQUENCE II

PRF			1013	1013	931	931	1013	1150	1013	1150	1150	931	1150	931
Attenuation (dB)			48	12	24	12	24	12	36	36	24	36	48	48
ATC	Display													
No.	1	2												
1		x	1	1	1	1	1	1	0	1	1	1	1	1
2	x		1	1	1	1	1	1	1	1	1	1	1	1
3		x	0	1	0	1	1	0	1	1	0	1	1	1
4	x		1	0	0	0	0	0	1	0	0	1	1	1
5	x		1	0	1	0	1	0	1	1	0	1	1	1
6		x	1	0	0	0	0	0	0	0	0	0	0	0
7	x		1	0	1	0	0	0	0	0	0	0	0	0
8		x	1	1	1	1	1	0	1	1	1	1	1	1
9	x		1	0	0	0	1	0	1	1	1	1	1	1
10		x	1	0	0	0	0	0	0	0	1	0	1	1
11		x	1	0	0	0	0	0	0	1	1	1	1	1
Average			*.91	.36	.45	.36	.55	.18	.55	.64	.55	.73	.82	.82
Total Changes/ + Changes				8/1	5/0	8/1	6/1	8/0	6/1	5/1				
Reject				x	x	x		x						

NOTE: Rejection Based on Binomial Test for Equal Changes at the .05 Level (see text)
* Reference Cases 1 - Accept, 0 - Reject

The probability expression for this assumption is:
P (+changes) = P (-changes) = 1/2.

This is implemented by noting the case from each sequence that received the highest ratio of controllers to accept handoffs. Each is used as the reference for its sequence, thus keeping all other factors the same.

Consulting table 12, which contains the raw scores for the testing, it is noted that for sequence 1, the reference is 1013 prf/48 dB with an acceptance ratio of 0.91 (931 prf/12 dB, with a value of 0.90 is not used since it has only 10 entries). In sequence 2 a similar acceptance ratio of 0.91 is found for the case of 1013 prf/12 dB. To determine if, in going from the reference cases to the others in the same sequence, there has been a significant increase in the number of rejections compared to the total number of changes, a one-tailed test is performed. Thus:

H_o : P (+ changes) = P (- changes)
H_1 : P (+ changes) < P (- changes)

The hypothesis that both conditions are equivalent is rejected if there are too few positive changes. The test is performed by consulting a binomial test table (reference 8) and setting the significance at the 0.05 level.

If for a total number of changes the probability of observing a given number of positive changes is less than 0.05, the original hypothesis is rejected. Summarizing the binomial tables, the conditions for rejection are listed in table 13.

TABLE 13. 0.05 LEVEL REJECTION CASES FOR P(+CHANGES)=P(-CHANGES)

Total Number of Changes	Number of Positive Changes: 0	1
5	x	
6	x	
7	x	
8	x	x
9	x	x
10	x	x
11	x	x

No rejections occur when the number of positive changes are 2 and 3.

The total number of changes compared to the respective reference cases have been recorded in table 12 along with the number of positive changes. In cases where the total number of changes is less than five, no entry has been made since rejection cannot occur at the 0.05 level with that small a sample. The conditions that fulfill the requirements for rejection have been indicated in table 12 and recorded in table 11. As seen in table 11, the six cases rejected all lie in the upper quarter of the values generated for the two indices.

In comparing the decrease in ratings for nonfluctuating strong targets with the acceptance of handoffs of equally strong targets, the latter test rejection occurs at higher values for both indices. Although the reference selected was an interference case, the high percentage of acceptance involved (90 percent) indicates that the true relationship to interference will not be very different. As such, the acceptance of handoffs should still require interference levels higher than those of the decrease in target ratings for rejection.

PERCENT OF WATCH.

This measure is based on each controller's assessment of the percentage of a watch that he would tolerate an interference condition with no reduction in workload. The assessment is calculated in 25-percent increments. The raw scores are coded in table 14 from 1 to 4, each representing a 25-percent increment. The mean for each case, in percent, is shown and plotted in figures 22 and 23 as a function of the N and M indices respectively. In both figures a power curve has been fitted to the results by performing a least squares fit to the log form of the expression.

To clarify, the log of $y = ax^b$ (reference 11) is:

$$\ln y = \ln a + b \ln x$$

The linear regression expressions presented earlier are used with the following substitutions:

$y = \ln y$
$x = \ln x$
$a = \ln a$
b remains unchanged

The resulting expressions for the regression terms are:

$$b = \frac{\Sigma(\ln x)(\ln y) - \frac{(\Sigma \ln x)(\Sigma \ln y)}{n}}{\Sigma(\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}}$$

$$a = \exp\left[\frac{\Sigma \ln y}{n} - b\,\frac{\Sigma \ln x}{n}\right]$$

The results for the individual terms are presented in table 15. The correlation coefficients are similarly found to be:

$$r = \frac{\left[\Sigma(\ln x)(\ln y) - \frac{(\Sigma \ln x)(\Sigma \ln y)}{n}\right]^2}{\sqrt{\left[\Sigma(\ln x)^2 - \frac{(\Sigma \ln x)^2}{n}\right]\left[\Sigma(\ln y)^2 - \frac{(\Sigma \ln y)^2}{n}\right]}}$$

TABLE 14. PERCENT OF WATCH THAT CONSTANT INTERFERENCE WOULD BE TOLERATED

SEQUENCE I

PRF			931	1150	1013	931	1013	1013	931	1150	1013	931	1150	1150
Attenuation (dB)			12	24	48	36	12	24	24	12	36	48	36	48
ATC No.	Display 1	Display 2												
1	x		2	2	4	2	1	0	3	1	2	3	3	3
2		x	2	2	3	1	1	1	2	1	2	3	2	3
3	x		0	0	2	0	0	0	0	0	0	0	0	0
4		x	0	0	4	2	0	0	0	0	3	4	2	4
5		x	1	1	2	2	0	1	1	0	2	3	2	3
6	x		-	0	1	0	0	0	0	0	0	0	0	1
7		x	0	0	2	0	0	0	0	0	0	0	0	0
8	x		0	0	0	0	0	0	0	0	0	0	0	0
9		x	0	0	1	1	0	0	1	0	1	2	1	1
10	x		0	0	1	0	0	0	0	0	2	1	0	0
11		x	0	0	2	1	0	0	0	0	1	3	1	1
Average x25 = % of Watch			13	11	*50	21	5	5	16	5	30	43	25	36
Total Change/ + Changes			9/0	10/0		8/0	10/0	10/0	9/0	10/0	8/1	7/3	8/0	6/1
Reject			x	x		x	x	x	x	x	x		x	

Sequence II

PRF			1013	1013	931	931	1013	1150	1013	1150	1150	931	1150	931
Attenuation (dB)			48	12	24	12	24	12	36	36	24	36	48	48
ATC No.	Display 1	Display 2												
1		x	4	1	2	1	2	1	3	3	2	3	4	4
2	x		1	0	1	0	0	0	0	1	0	2	3	4
3		x	1	1	0	1	1	1	1	1	1	1	1	1
4	x		4	0	0	0	0	0	0	0	0	2	4	4
5	x		2	1	2	0	1	0	1	2	0	3	2	3
6		x	0	0	0	0	0	0	0	0	0	0	0	0
7	x		0	0	0	0	0	0	0	0	0	0	0	1
8		x	1	0	0	0	0	0	1	1	0	1	1	2
9	x		1	0	0	0	1	0	1	1	0	1	2	2
10		x	3	0	0	0	0	0	0	0	0	0	1	1
11		x	3	0	0	0	0	0	1	2	1	4	4	4
Average x25 = % of Watch			45	7	11	5	11	5	18	25	9	39	50	*59
Total Changes/ + Changes			7/1	9/0	10/0	9/0	9/0	9/0	9/0	9/0	9/0	9/0	4/0	
Reject				x	x	x	x	x	x	x	x	x		

NOTE: Rejection Based on Binomial Test for Equal Changes at the .05 Level (see text)
* Reference Entries are in Quarters of a Watch, Averages are in Percent

TABLE 15. SUMMARY OF PERCENT OF WATCH DATA VERSUS N AND M

N#	Proportion of Watch	Cases Rejected	M#	Proportion of Watch	Cases Rejected
3.176	.59	Reference	9.164	.30	x
3.274	.50		9.171	.43	
3.756	.39	x	9.352	.50	
3.790	.18	x	9.354	.59	Reference
4.125	.25	x	9.359	.36	
4.337	.43		9.402	.21	x
4.406	.36		9.409	.50	Reference
4.416	.50	Reference	9.855	.39	x
4.968	.30	x	9.995	.25	x
5.062	.21	x	10.389	.25	x
5.270	.25	x	10.430	.18	x
5.802	.11	x	10.818	.45	
6.774	.09	x	10.902	.16	x
6.843	.16	x	11.427	.05	x
7.016	.05	x	11.944	.11	x
7.223	.11	x	12.256	.11	x
7.987	.11	x	12.350	.11	x
8.106	.07	x	12.913	.09	x
9.269	.13	x	13.488	.05	x
9.414	.05	x	14.122	.05	x
9.470	.05	x	14.185	.07	x
9.664	.05	x	14.298	.13	x
10.562	.05	x	15.516	.05	x
			16.800	.05	x

Intermediate Calculations for Power Curve Fits

N	M
n=23	24
$\Sigma \ln x = 40.770$	58.286
$\Sigma \ln y = 42.514$	-43.312
$\Sigma(\ln x)(\ln y) = -81.691$	-108.378
$\Sigma(\ln x)^2 = 75.390$	142.348
$\Sigma(\ln y)^2 = 94.430$	95.068
$a = 5.735$	2859,761
$b = 2.028$	-4.020
$r = -.90$	-.87

Power Curve

$y = ax^b$
x = index number
y = proportion of watch

The correlation coefficients determined for the N and M indices are respectively:

$r_N = -0.90$
$r_M = -0.87$

The t tests for both coefficients are performed as before. The coefficient of the N index is:

$$t = r\sqrt{\frac{n-2}{1-r^2}} = -0.90\sqrt{\frac{23-2}{1-(0.90)^2}} = -9.46$$

For n-2 degrees of freedom, which in this case equals 21 and a one-tailed test, r is significant at in excess of the 0.0005 level ($|-9.46| > 3.819$ reference 8). Therefore r is significant at the .05 level (t=1.721). Similarly, the coefficient of the M index is tested using the t value.

$$t = -.087\sqrt{\frac{24-2}{1-(0.87)^2}} = -8.28$$

A one-tailed test for n-2 degrees of freedom, i.e., 22, reveals that this correlation is significant at in excess of the 0.0005 level ($|-8.28| > 3.792$ reference 8), and therefore significant at the 0.05 level (t=1.717).

Since the chance of observing either of these correlations as samples of populations where the correlations are zero (no correlation exists) is less than 5 percent, both correlations are significant.

The expressions used for generating the curves in figures 22 and 23 are respectively:

Percent of watch $= 574N^{-2.03}$ and Percent of watch $= 285{,}976\ M^{-4.02}$

The above expressions, as was the case for those developed for the handoff test, cannot be regarded as the complete descriptors of the relationships between the indices and the respective measures. The forms of the relationships, however, are significant as evidenced by the t tests. This accounts, in part, for the relative changes in responses to variations in interference. The extent to which these changes are accounted for is determined by the magnitude of the correlation coefficients.

As with the handoff tests, certain baseline information was lacking. However, by implementing the same test used previously, those cases that would be obviously unacceptable under this performance measure can be isolated. Specifically, it is intended to eliminate those cases which are significantly lower than the highest scored case available. To restate the test, it is assumed that any changes in ratings (percent of watch) that controllers make in going from one condition to another will tend to nullify each other and the median will remain constant. If there is a disproportionate number of decreased ratings compared to the total number of changed ratings, that case is rejected as having a negative effect upon the performance measure.

The references for these comparisons, one for each sequence, are those that represent the highest average for the percent of watch (table 14). The references are 50 percent for sequence 1 and 59 percent for sequence 2. Comparing the reference cases with every other case in the same sequence, the total number of changes as well as the number of positive changes are noted. In table 14, the column headed 931 prf/12 dB has a total number of nine changes from the 1013 prf/48 dB reference. The missing entry for controller 6 is considered as no change, and therefore is not counted. There are no entries higher than the reference, and consequently no positive changes. The results of these comparisons are listed below each interference condition. Consulting the 0.05 level rejection cases listed in table 13, the conditions that show a significant decline in percent of watch tolerance can be rejected. These cases are indicated in table 14 and recorded in table 15. In the latter table, all of the nonrejected cases occur in the lower half of the ranges of each index.

Excluding the reference cases, three conditions are not rejected under the N index, while four escape rejection under the M classification. The lowest levels at which rejection occurs under both indices are 3.8 for N and 9.2 for M. Although these are the same lower levels of rejection under the decrease in rating measure, and in spite of some overlap of nonrejected cases under the two tests, the two measures cannot be regarded as equivalent based on the information available. This arises from the fact that the references for percent of watch were levels where the test subjects indicated that the interference would be tolerated for 50 to 59 percent of the time. It should be noted that criteria that use this measure and specify a significantly higher tolerance, say 80 to 90 percent on the part of the controllers, would result in rejection of all the levels presented. It would then constitute a lower threshold level than does the decrease in target ratings. This assumes that the results of that test are not severely altered by fluctuating targets.

OVERALL RATING.

The final measure obtained is based on the controller's overall evaluation of the interference condition. This includes the interference/display/target combinations used in the testing. The rating that was implemented was the condition under which the controller would work with the particular case throughout an entire watch. The possible alternatives were: (1) no difficulty, (2) reduced workload, (3) unacceptable.

This measure represents the most subjective of those presented so far. One aspect of the possible responses, however, can be used to assess the interference conditions. If it can be asserted a threshold must be one in which all controllers had difficulty, then those cases can be eliminated from further consideration. This represents a very conservative guideline in terms of favoring the presence of interference. Following this guide, any response that the interference presented no difficulty, would not rule out that particular condition.

Implementing this rule of thumb, it is noted whether, under any condition, at least one "no difficulty" response occurred. These conditions, i.e., those not rejected, are found from the list of controller responses in table 16.

The proportion of controllers making each decision are listed in table 17 with the cases rejected under the foregoing scheme noted accordingly. This rejection scheme is of limited value in predicting a threshold for larger groups. This arises from insufficient detail in evaluating the interference conditions to generate an adequate probability distribution. To correct this deficiency, a finer grain rating scale and a larger number of test subjects would be required. Then, rejections could be based on a more realistic enumeration of the individual ratings.

To the extent of the particular test group, the rejection region for both indices occur at higher values than for the target rating decrease and the percent of watch measures. In comparison with the willingness to accept handoffs, the interference ratings occur at slightly lower index values.

Correlation between this measure and the two indices was not attempted due to the fact that the question, as addressed to the subjects, made reference to the display. That is, where the questions concerning the acceptance of handoffs and percent of watch specifically addressed only interference, the evaluation responses must be considered to have incorporated some judgement with respect to the display. As a consequence, the visibility of the weak targets during the rating phase may have been contributory to the interference evaluation. This represents a very fine but necessary distinction.

REVIEW OF THE INTERFERENCE INDICES N AND M.

In generating the modified index M, there was concern of the possible effects of pulse stretching during receiver saturation. As such, and under the assumption that its effect would be linear in form, as in the case of the index N, correlations were drawn between M and the respective measures. Reviewing the results of these correlations, the following observations can be made:

1. The decrease in weak target ratings did not confirm a significant correlation with M as they did with N.

2. Acceptance of handoffs was only slightly better correlated in the sample with M than N.

3. Correlation between percent of watch and M is, at most, equal to that obtained with N.

Since there is no overwhelming indication of superior correlation with M than N, the effects of pulse stretching as a major factor in this test can be negated.

TABLE 16. INTERFERENCE RATING SCORES

SEQUENCE I

ATC No.	Display 1	Display 2												
PRF			931	1150	1013	931	1013	1013	931	1150	1013	931	1150	1150
Attenuation (dB)			12	24	48	36	12	24	24	12	36	48	36	48
1	x		2	2	1	-	3	3	2	2	2	1	2	2
2		x	2	2	2	2	3	2	2	3	2	2	2	2
3	x		3	3	2	3	3	3	3	3	3	2	2	3
4		x	3	3	1	3	3	3	3	3	2	1	2	1
5		x	3	3	1	2	3	2	2	3	3	2	2	2
6	x		-	3	2	3	3	3	3	3	3	2	3	2
7		x	3	3	2	3	3	3	3	3	3	3	3	3
8	x		3	3	3	3	3	3	3	3	3	3	3	2
9		x	3	3	2	2	3	3	2	3	2	2	2	2
10	x		3	3	2	3	3	3	3	3	2	2	3	2
11		x	3	2	2	2	3	3	3	2	2	2	2	2

SEQUENCE II

ATC No.	Display 1	Display 2												
PRF			1013	1013	931	931	1013	1150	1013	1150	1150	931	1150	931
Attenuation (dB)			48	12	24	12	24	12	36	36	24	36	48	48
1		x	1	2	2	2	2	3	1	1	2	2	1	1
2	x		2	3	2	3	3	3	-	2	3	2	2	1
3		x	3	3	3	3	3	3	3	3	3	3	3	3
4	x		2	3	3	3	3	3	2	2	3	2	1	1
5	x		2	3	2	3	3	3	2	2	3	2	2	2
6		x	2	3	3	3	3	3	3	3	3	3	3	3
7	x		2	3	3	3	3	3	3	3	3	3	3	3
8		x	2	3	3	3	3	3	3	3	3	3	2	2
9	x		2	3	3	3	2	3	2	2	3	2	2	2
10		x	2	3	3	3	3	3	3	3	3	3	2	2
11		x	2	3	3	3	3	3	2	2	2	1	1	1

NOTE: 1 - No Difficulty, 2 - Reduced Workload, 3 - Unacceptable

TABLE 17. SUMMARY OF INTERFERENCE RATING DATA VERSUS N AND M

N#	Proportion Giving Particular Rating			Cases Rejected Total Agreement of Some Difficulty	M#	Proportion Giving Particulat Rating			Cases Rejected Total Agreement of Some Difficulty
	1	2	3			1	2	3	
3.176	.36	.36	.27		9.164	.00	.55	.45	x
3.274	.27	.45	.27		9.171	.18	.64	.18	
3.756	.09	.45	.45		9.352	.27	.45	.27	
3.790	.10	.40	.50		9.354	.36	.36	.27	
4.125	.09	.45	.45		9.359	.09	.73	.18	
4.337	.18	.64	.18		9.402	.00	.40	.60	x
4.406	.09	.73	.18		9.409	.27	.64	.09	
4.416	.27	.64	.09		9.855	.09	.45	.45	
4.968	.00	.55	.45	x	9.995	.00	.64	.36	x
5.062	.00	.40	.60	x	10.389	.09	.45	.45	
5.270	.00	.64	.36	x	10.430	.10	.40	.50	
5.802	.00	.18	.82	x	10.818	.09	.82	.09	
6.774	.00	.18	.82	x	10.902	.00	.36	.64	x
6.843	.00	.36	.64	x	11.427	.00	.18	.82	x
7.016	.00	.18	.82	x	11.944	.00	.18	.82	x
7.223	.00	.27	.73	x	12.256	.00	.27	.73	x
7.987	.00	.27	.73	x	12.350	.00	.27	.13	x
8.106	.00	.09	.91	x	12.913	.00	.18	.82	x
9.269	.00	.20	.80	x	13.488	.00	.09	.91	x
9.414	.00	.00	1.00	x	14.122	.00	.00	1.00	x
9.470	.00	.09	.91	x	14.185	.00	.09	.91	x
9.664	.00	.00	1.00	x	14.298	.00	.20	.80	x
10.562	.00	.18	.82	x	15.516	.00	.18	.82	x
					16.800	.00	.00	1.00	x

LIMITS OF INVESTIGATION

1. The cases studied were of a single interferer, fixed wedge, single pulse width variety.

2. Textural content of the interference cases were similar, possessing little unique visual characteristics such as strobing, solid spirals, crosshatching, etc.

3. The sample size of controllers was limited to 11 subjects and did not include individuals with limited "raw radar" experience.

4. Traffic samples were limited in variety with the controllers working primarily as observers, i.e., not vectoring targets.

5. Targets were of a nonscintillating type.

6. The effects of visual aids, such as maps, were not investigated.

7. The interference cases investigated did not go low enough in intensity to obtain absolute baseline data for the percent of watch and handoff measures.

8. The controller evaluation measure did not specifically isolate interference.

Due to the above limitations, application of the results derived to other than a limited number of field conditions must be done with extreme caution. In particular, the primary constraints of this investigation are the small number of test subjects and the uniformity of the interference conditions. Because of this and the lack of interference cases low enough in intensity to elicit complete agreement among the test controllers, the results can only be regarded as an upper limit for subsequent interference studies. This assertion rests heavily on the sample group having extensive backgrounds in the use of raw radar.

CONCLUSIONS

1. Significant correlations exist between the interference index N and the performance measures used in this investigation.

2. Correlation exists between the decrease in target ratings for both strong and weak nonfluctuating targets and increasing interference based on the Katz interference index N. The lowest level at which a significant decrease in ratings occur is at an N value of 3.8.

3. Correlation, which is in part explained by a linear relationship, exists between willingness to accept handoffs and the interference index N. Based on a 90-percent reference, 10 out of 11 test subjects, for the acceptance of handoffs, the lowest level at which a significant decline occurs is at an N value of 7.2.

4. A correlation, partially attributable to a power curve relationship, exists between the percent of watch that an interference condition would be tolerated and its N value. Based on a reference of interference being tolerated 50 to 59 percent of the time, the lowest level at which a significant decline occurs is at N=3.8.

5. The lowest level at which the test subjects were in total agreement that some difficulty would be experienced with the interference conditions occurred at N=5.0. This measure did not distinguish between interference and the interference /display/ target combination.

6. Correlations exist between the performance measures and the modified interference index M, with the possible exception of the decrease in weak nonfluctuating target ratings. The general equivalence of the correlations for the two indices does not support pulse stretching as a major factor in this study.

7. Although the rejected interference cases tended to occur at higher N values, the lowest level N investigated, approximately 3.2, was insufficient to provide consistently acceptible levels of interference.

RECOMMENDATIONS

1. Lower levels of interference should be investigated to provide an adequate number of data points and to ascertain the acceptible levels of interference.

2. The subject of controller performance measures should be addressed to provide a validated basis for subsequent efforts to establish criteria.

3. The range of interference patterns should be extended sufficiently to provide a more precise relationship with controller performance measures.

4. Effects on single-pulse sensitivity levels due to video mapping and other visual aids should be identified.

5. Any further investigations should use fluctuating targets to more accurately simulate a live aircraft environment.

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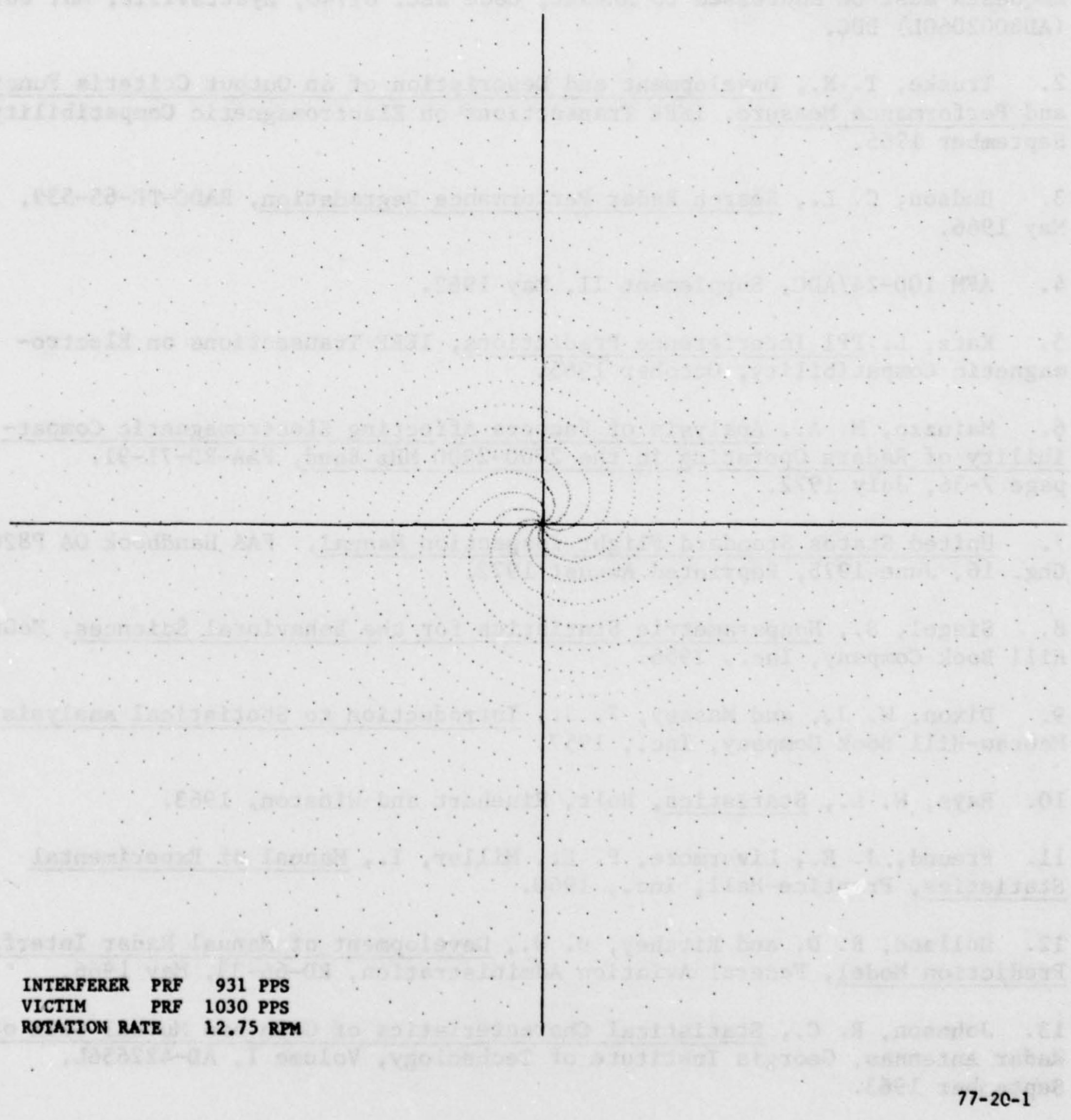


FIGURE 1. COMPUTER GENERATED PLOT 931 PPS

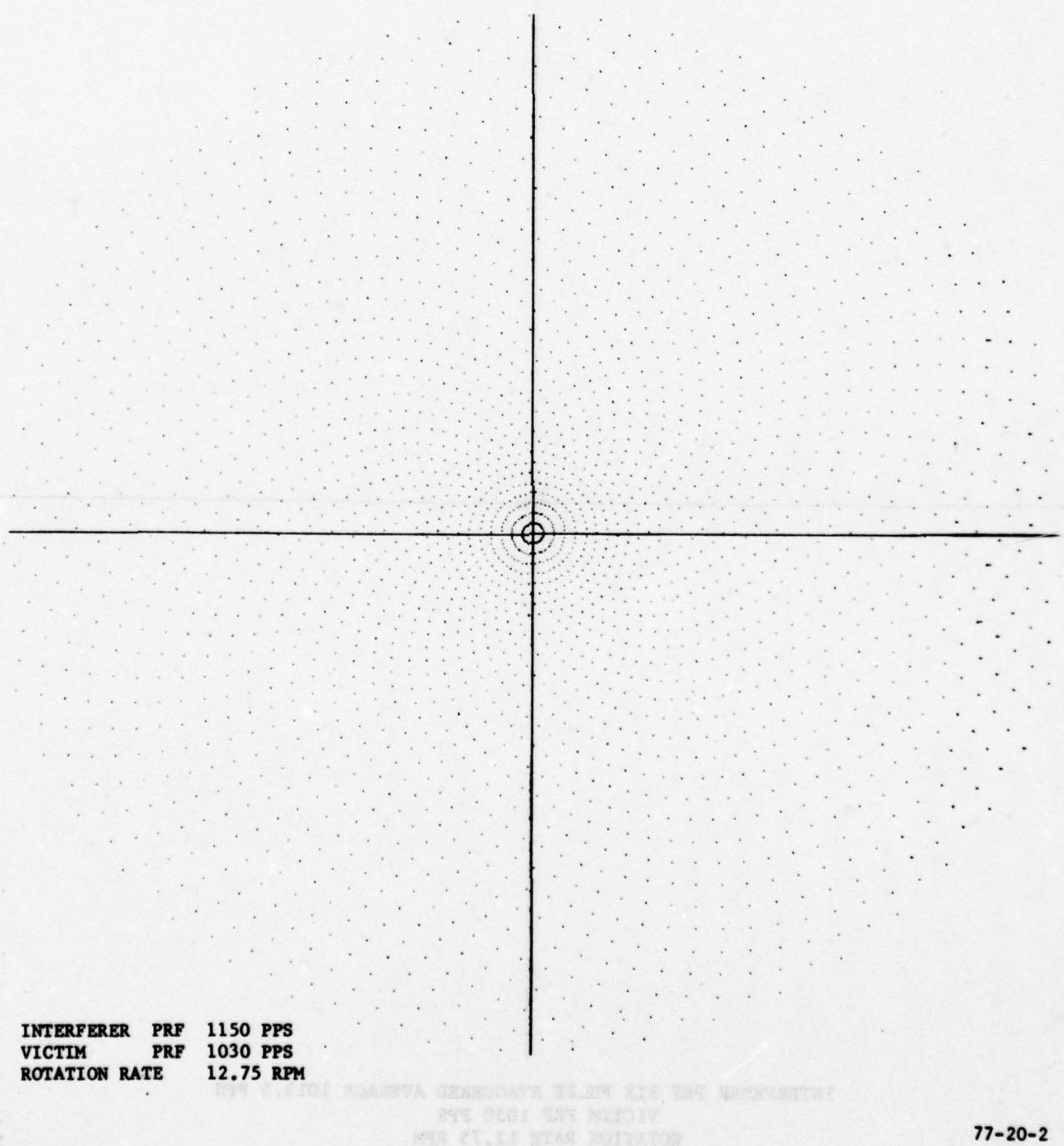
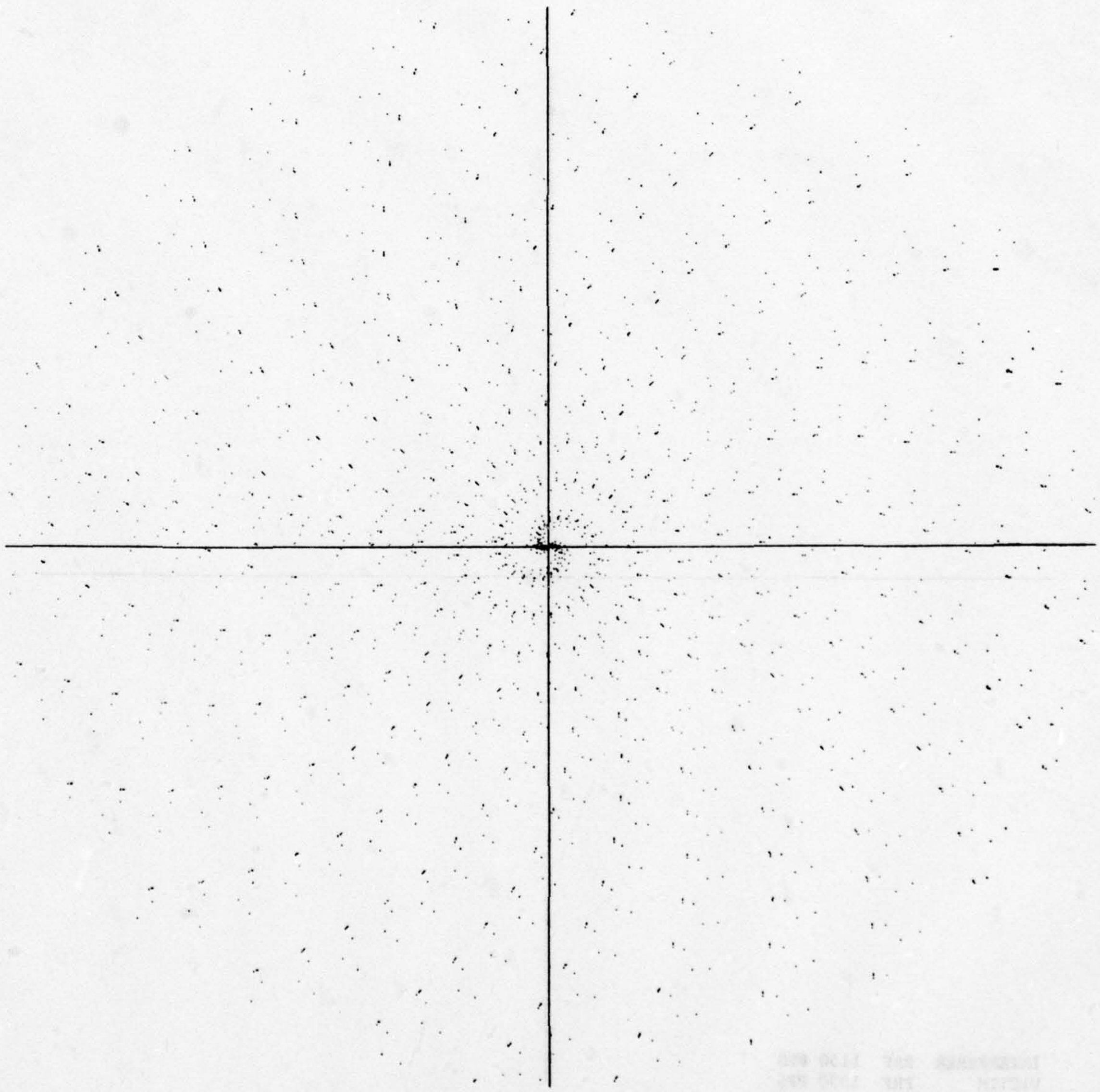


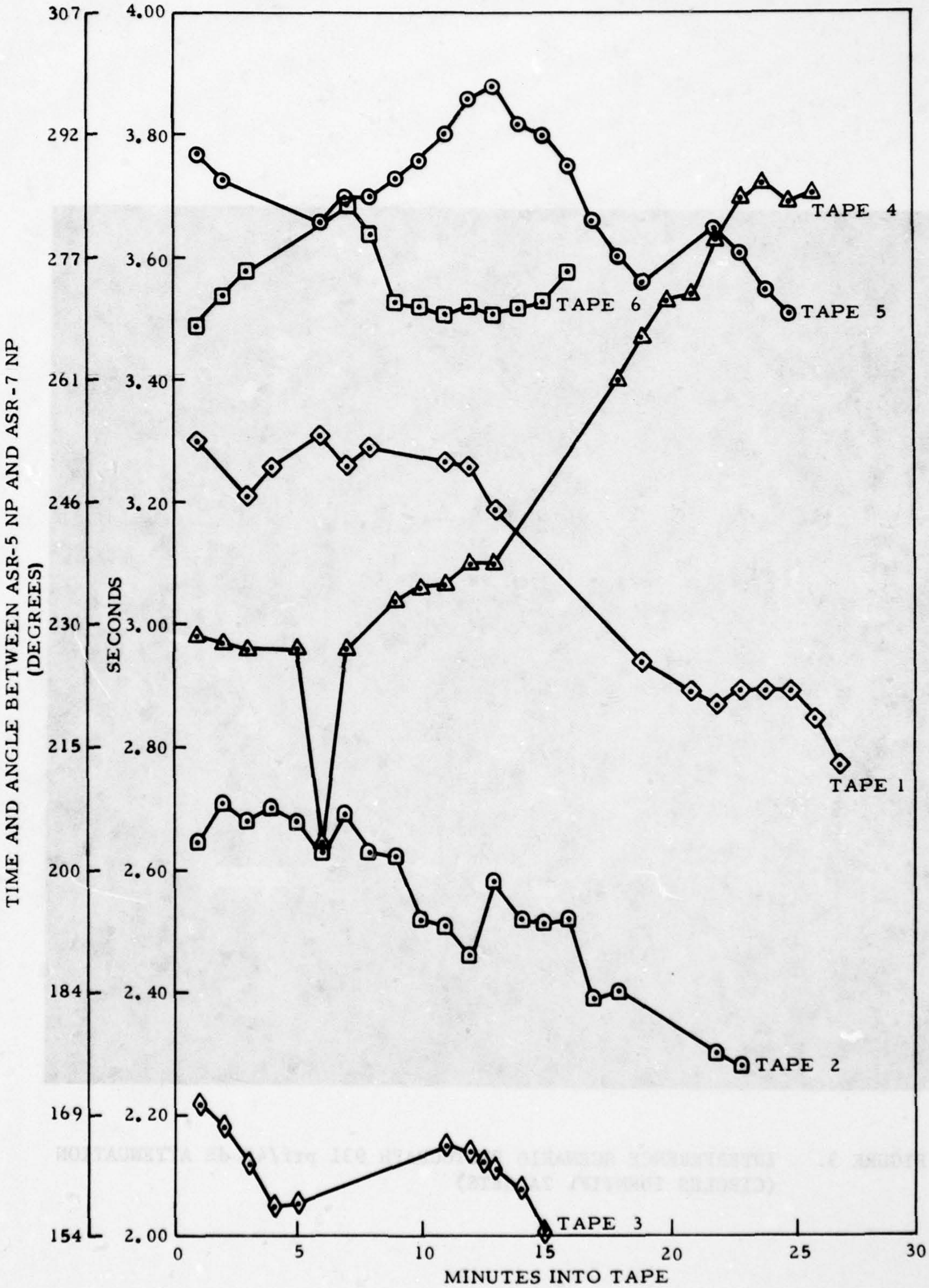
FIGURE 2. COMPUTER GENERATED PLOT 1150 PPS



INTERFERER PRF SIX PULSE STAGGERED AVERAGE 1013.5 PPS
VICTIM PRF 1030 PPS
ROTATION RATE 12.75 RPM

77-20-3

FIGURE 3. COMPUTER GENERATED PLOT 1013.5 PPS



77-20-4

FIGURE 4. NORTH PULSE DIFFERENTIAL BETWEEN ASR-5 AND ASR-7

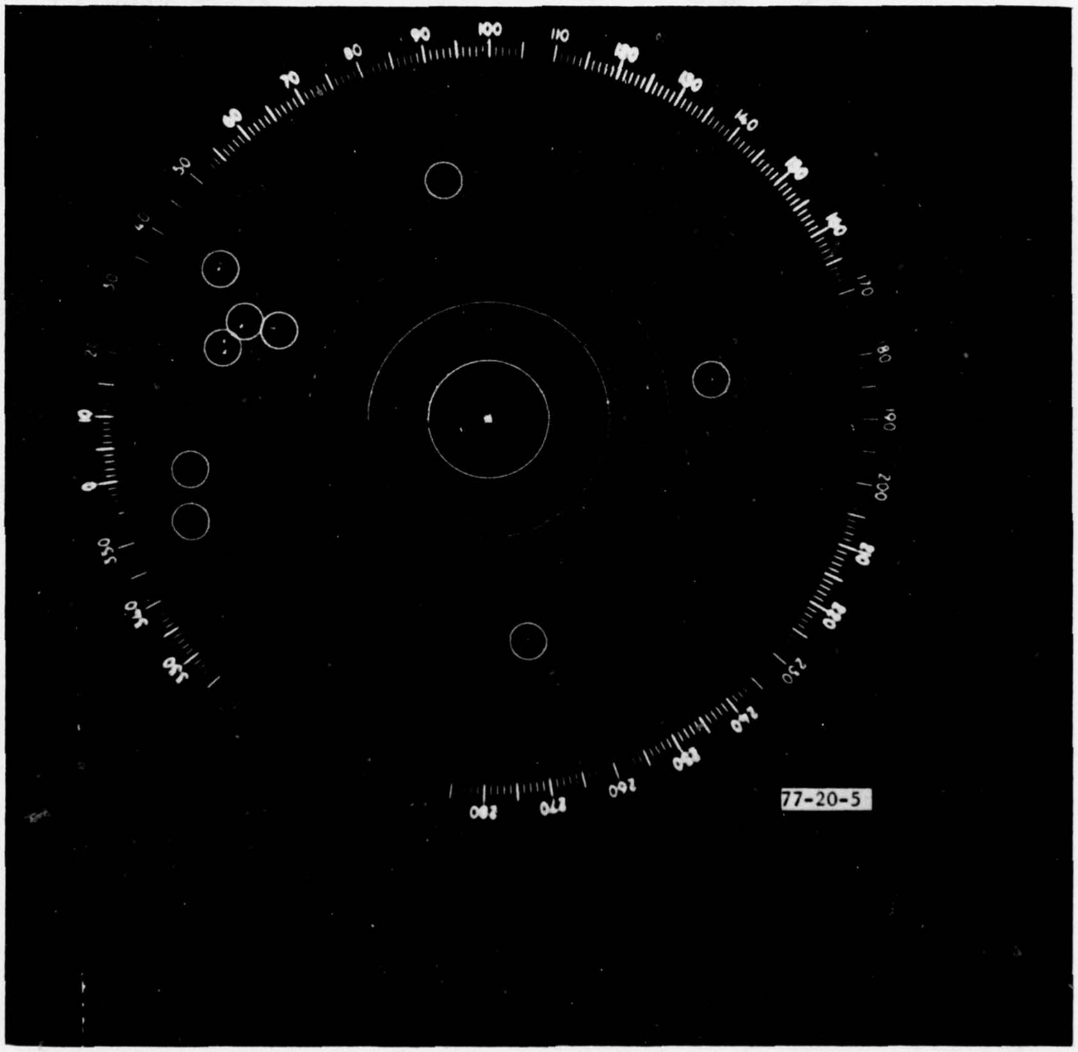


FIGURE 5. INTERFERENCE SCENARIO PHOTOGRAPH 931 prf/48 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

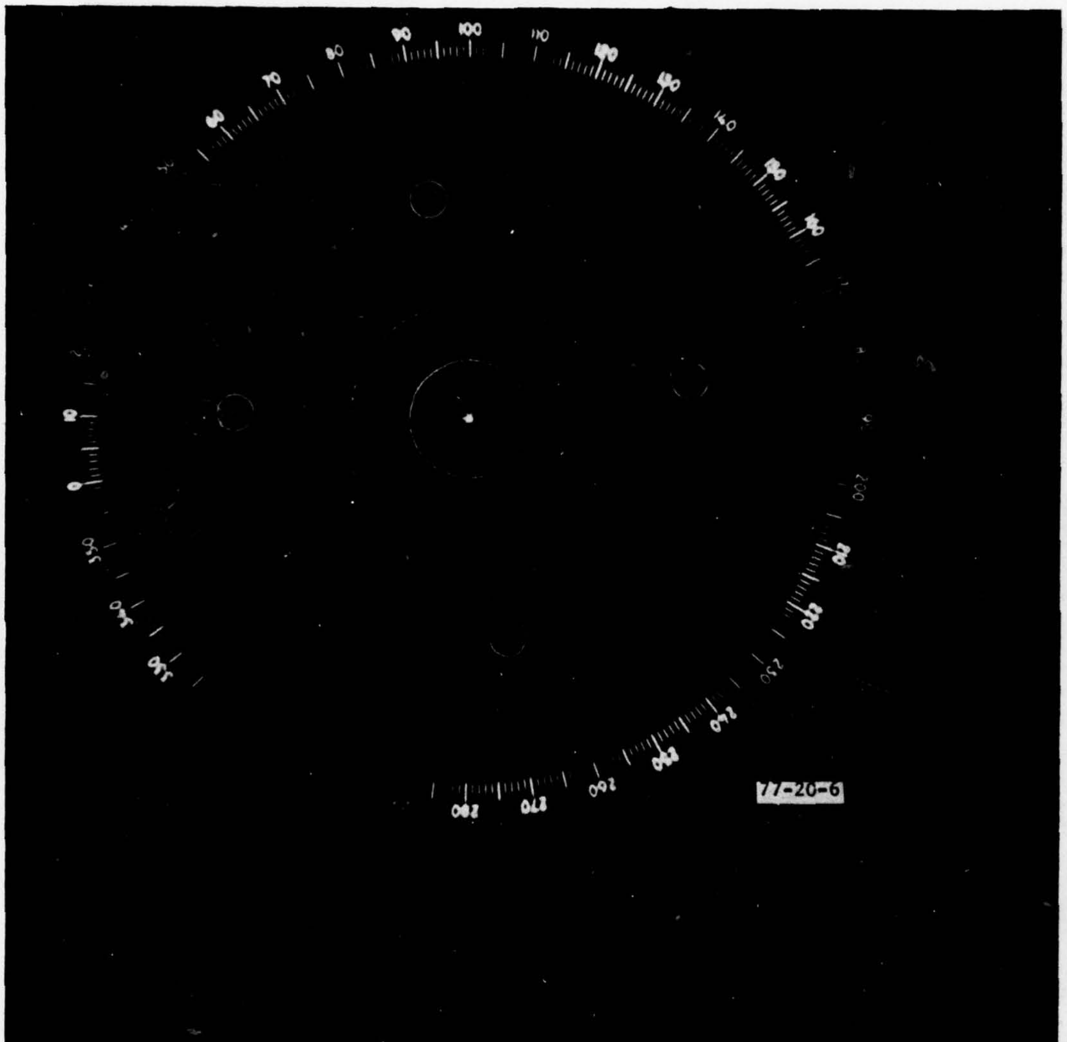


FIGURE 6. INTERFERENCE SCENARIO PHOTOGRAPH 931 prf/36 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

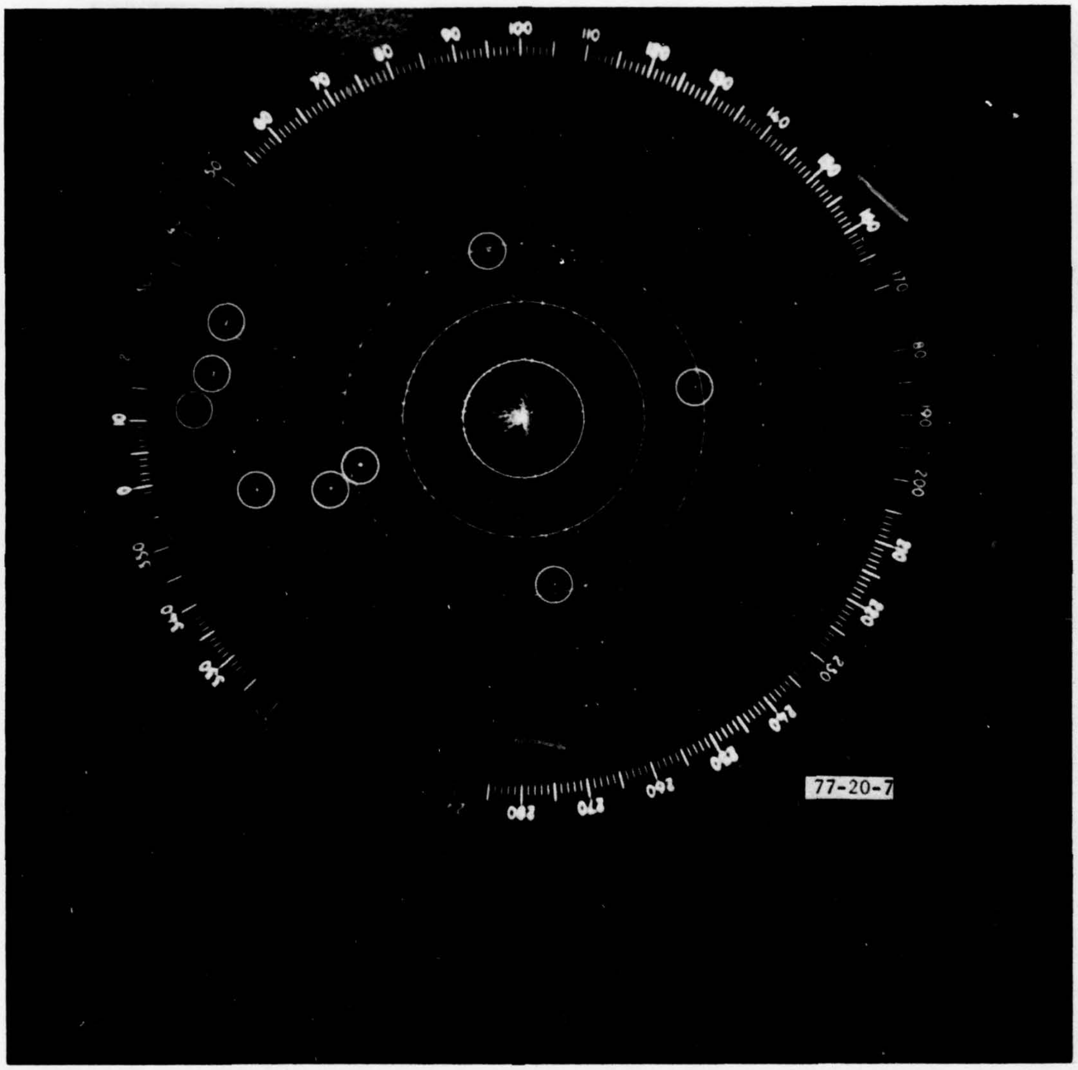


FIGURE 7. INTERFERENCE SCENARIO PHOTOGRAPH 931 prf/24 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

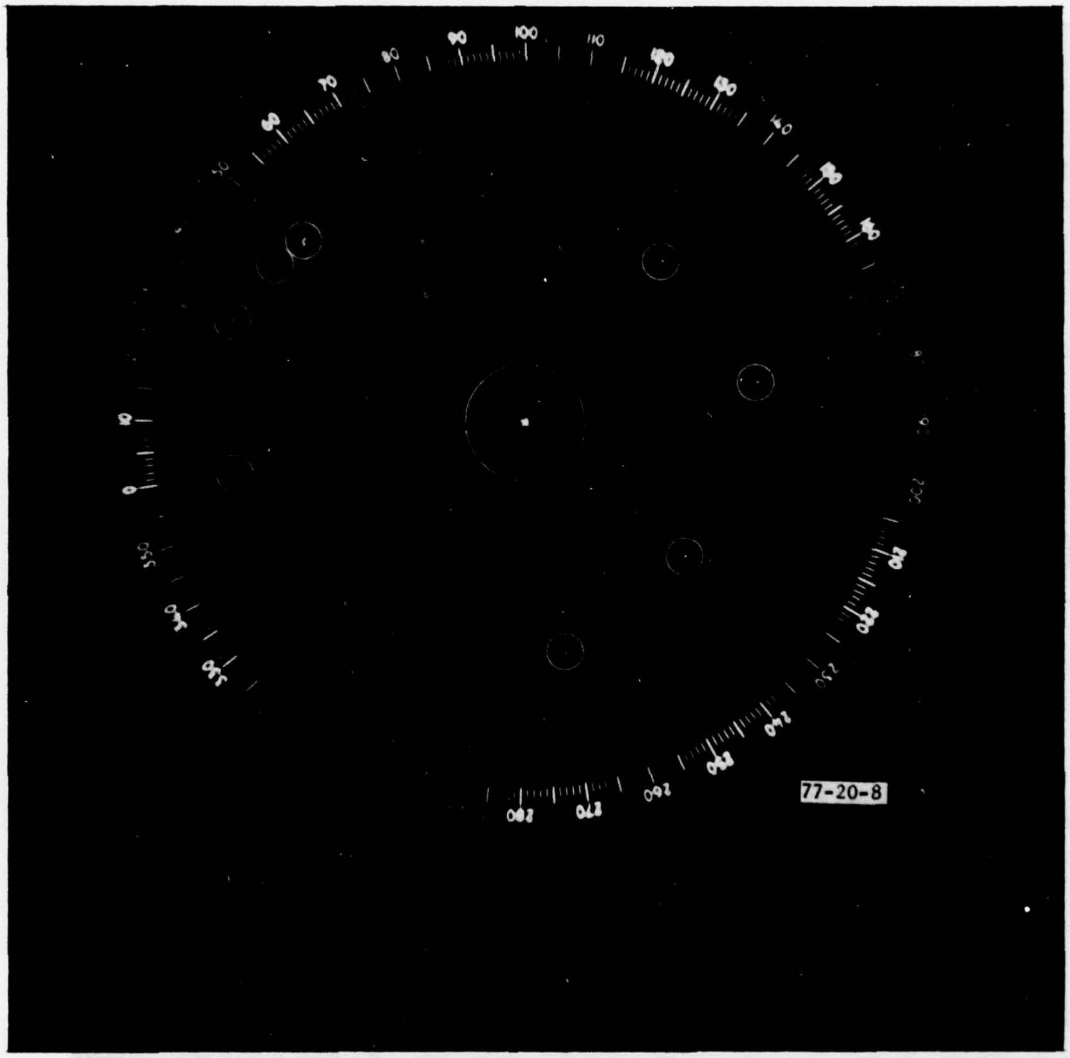


FIGURE 8. INTERFERENCE SCENARIO PHOTOGRAPH 1013.5 prf/48 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

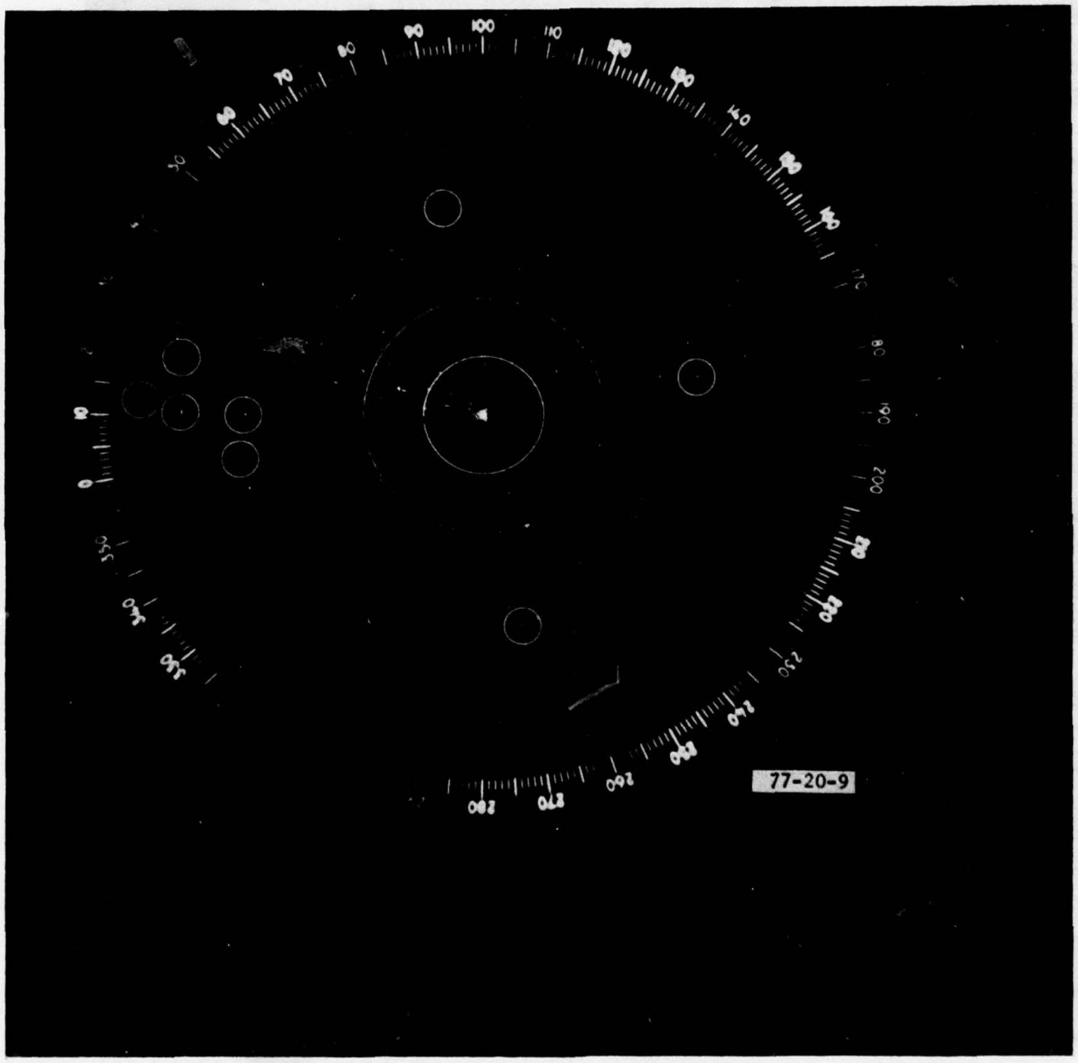


FIGURE 9. INTERFERENCE SCENARIO PHOTOGRAPH 1013.5 prf/36 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

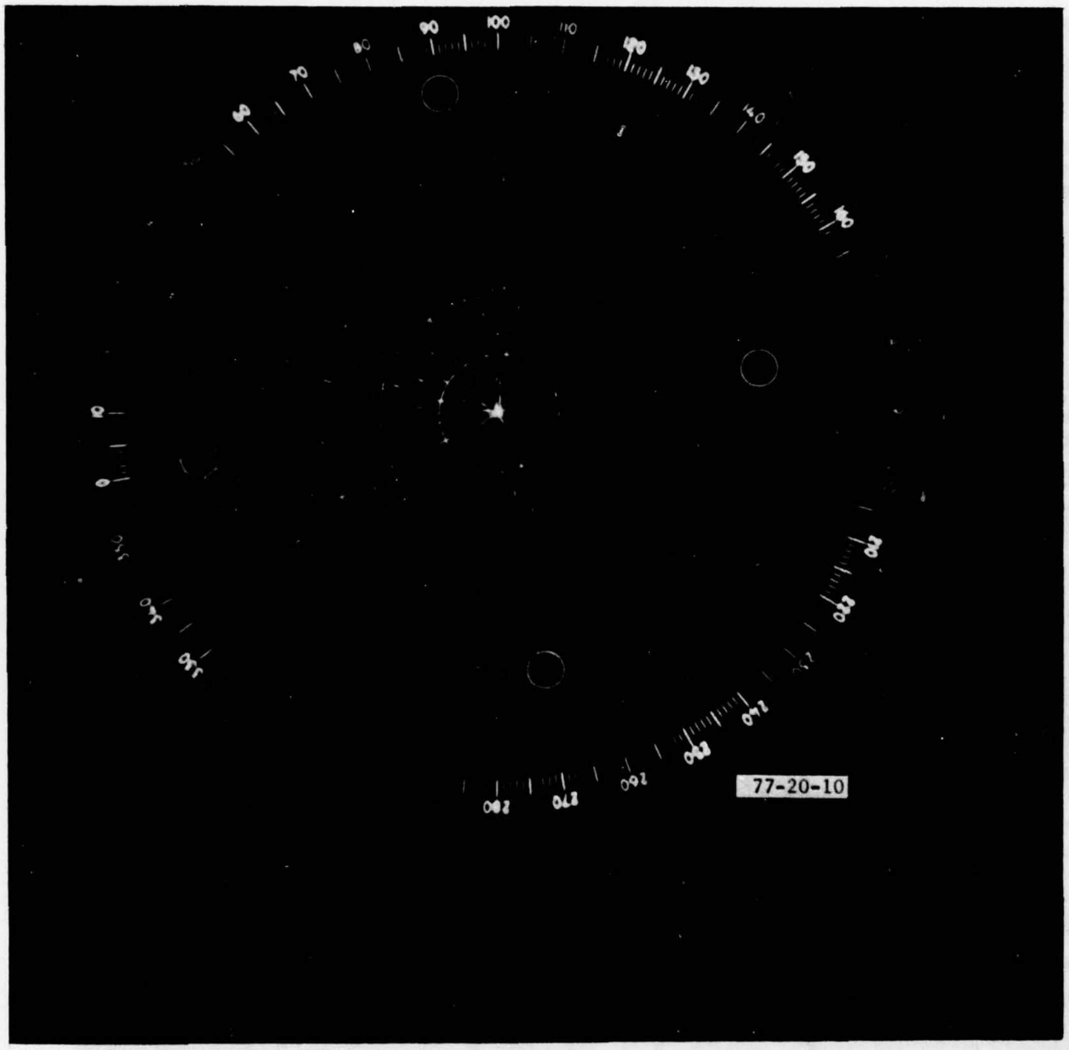


FIGURE 10. INTERFERENCE SCENARIO PHOTOGRAPH 1013.5 prf/24 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

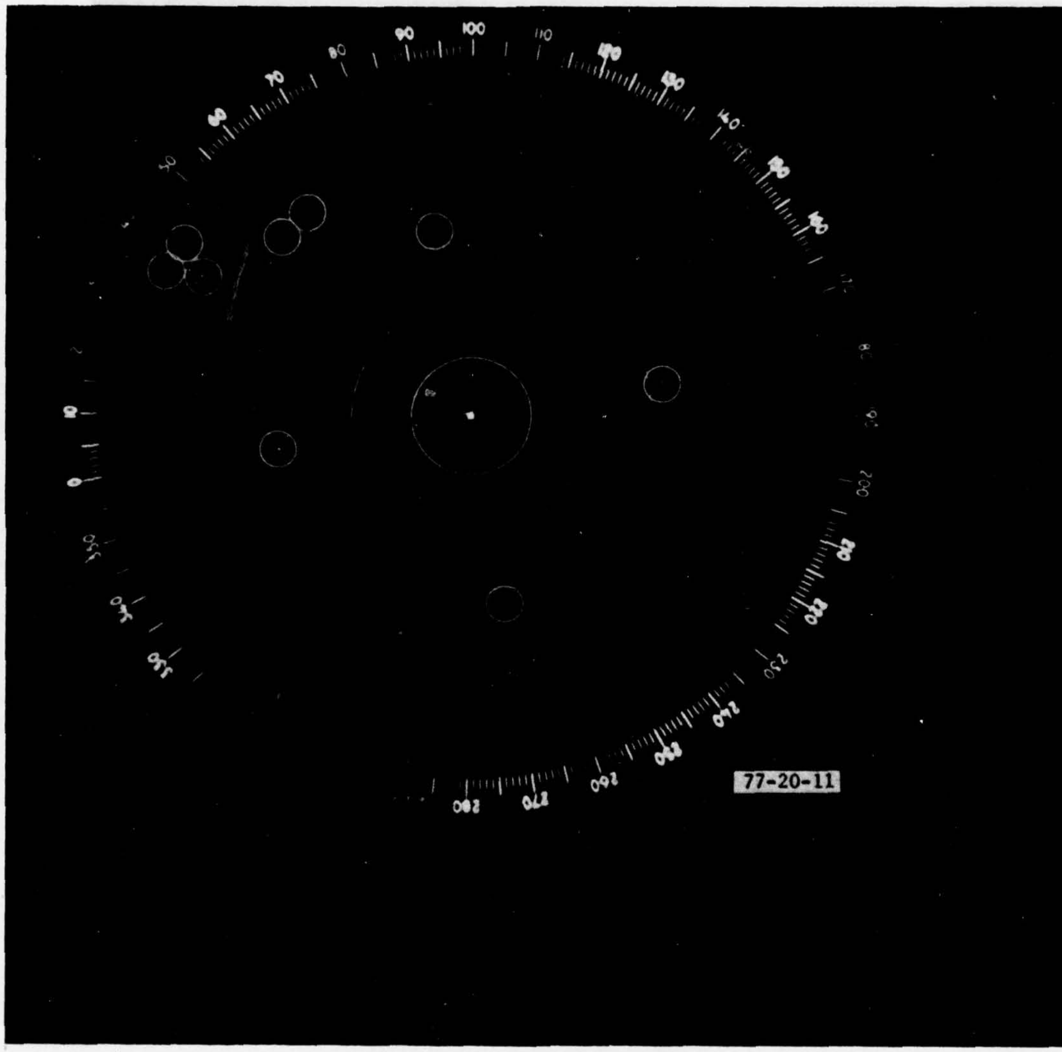


FIGURE 11. INTERFERENCE SCENARIO PHOTOGRAPH 1150 prf/48 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

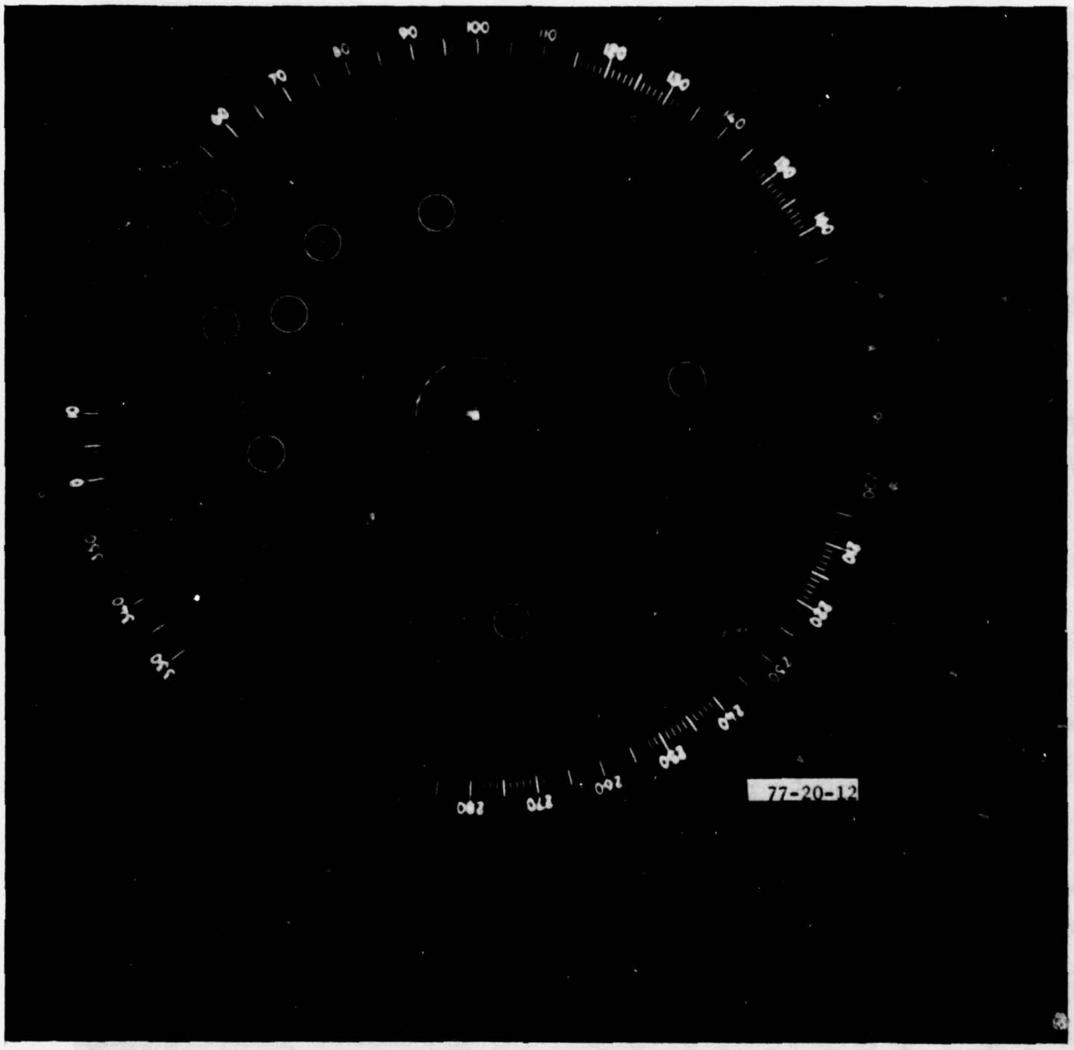


FIGURE 12. INTERFFRENCE SCENARIO PHOTOGRAPH 1150 prf/36 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

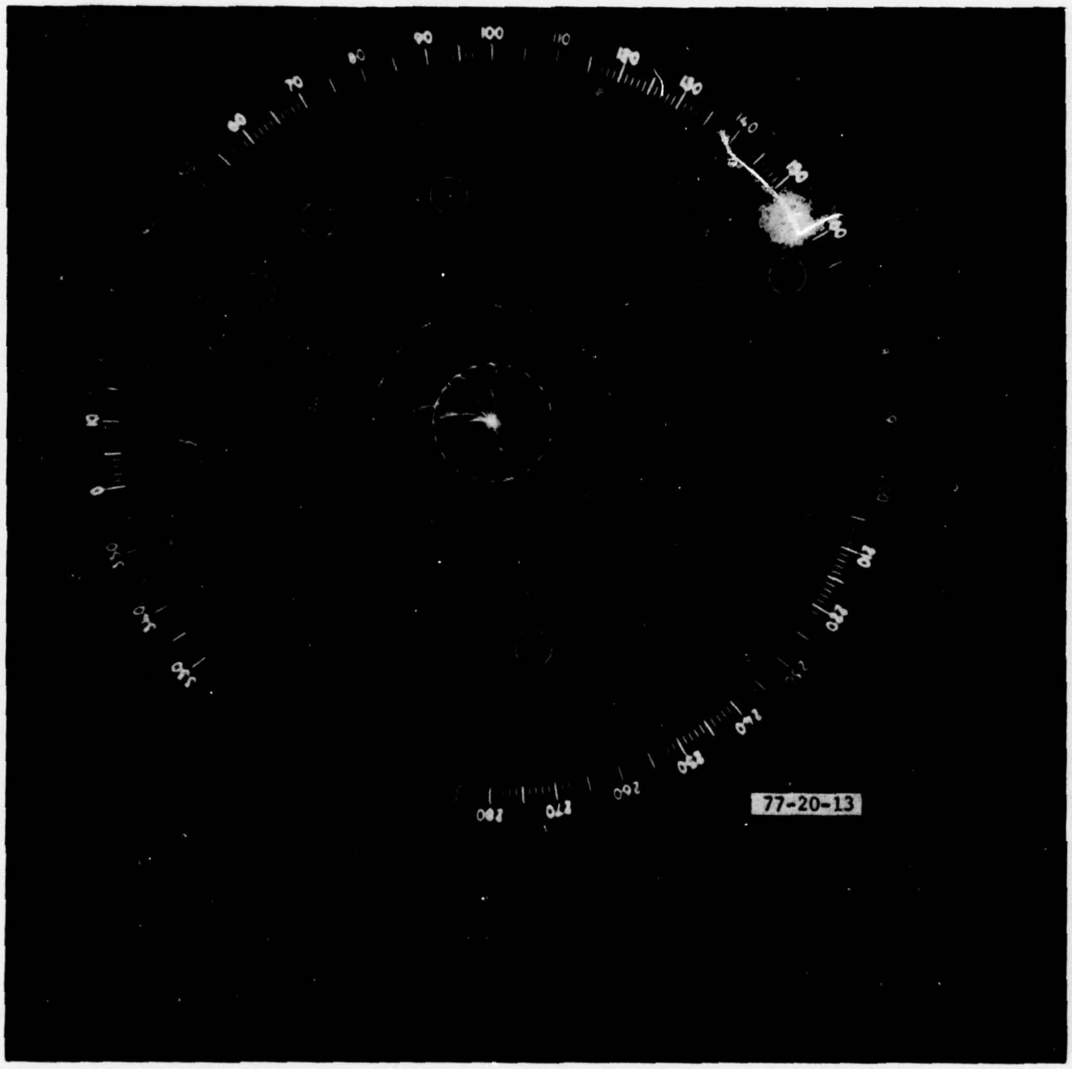


FIGURE 13. INTERFERENCE SCENARIO PHOTOGRAPH 1150 prf/24 dB ATTENUATION (CIRCLES IDENTIFY TARGETS)

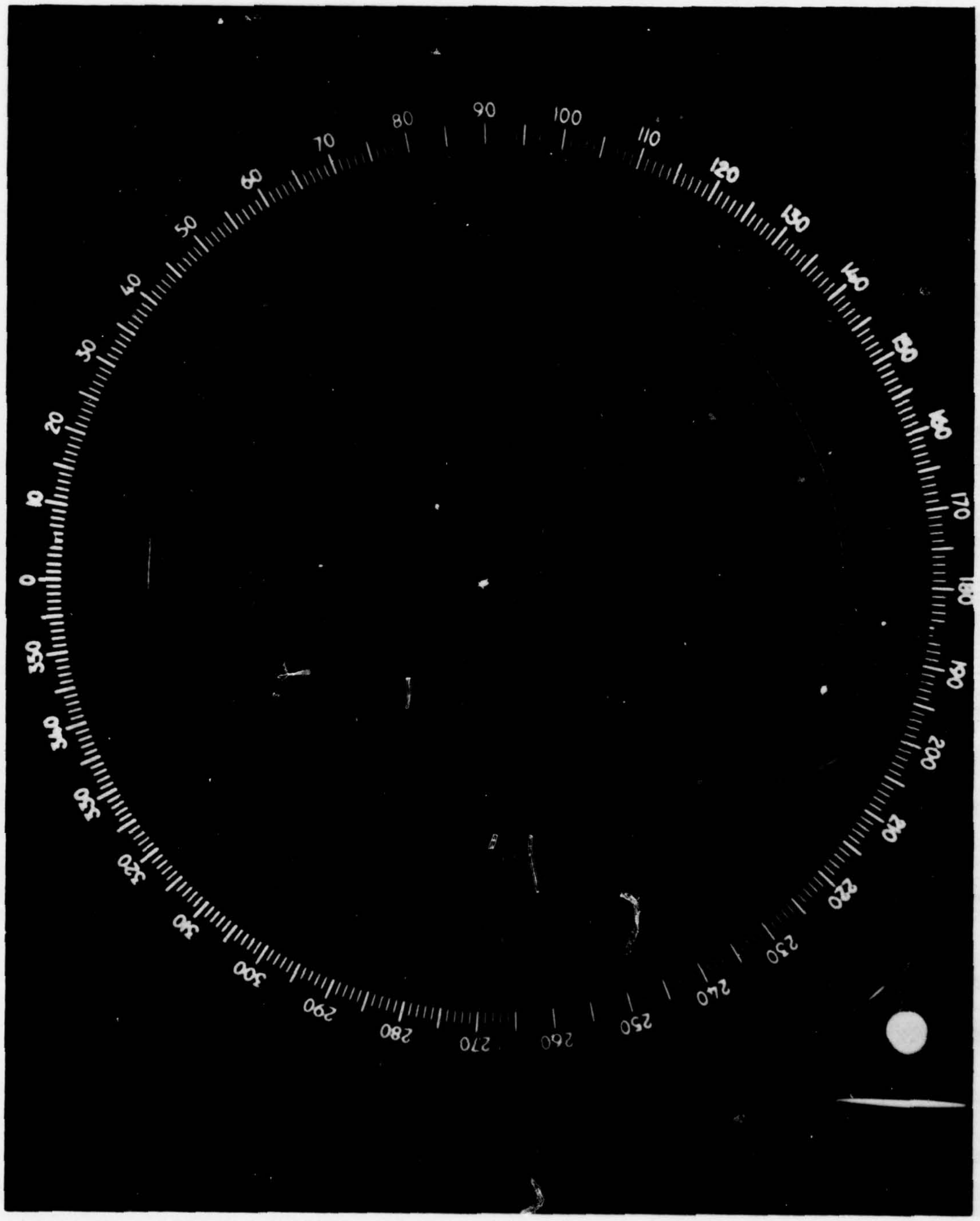


FIGURE 14. 30 SCANS SCENARIO BEACON TRACKS

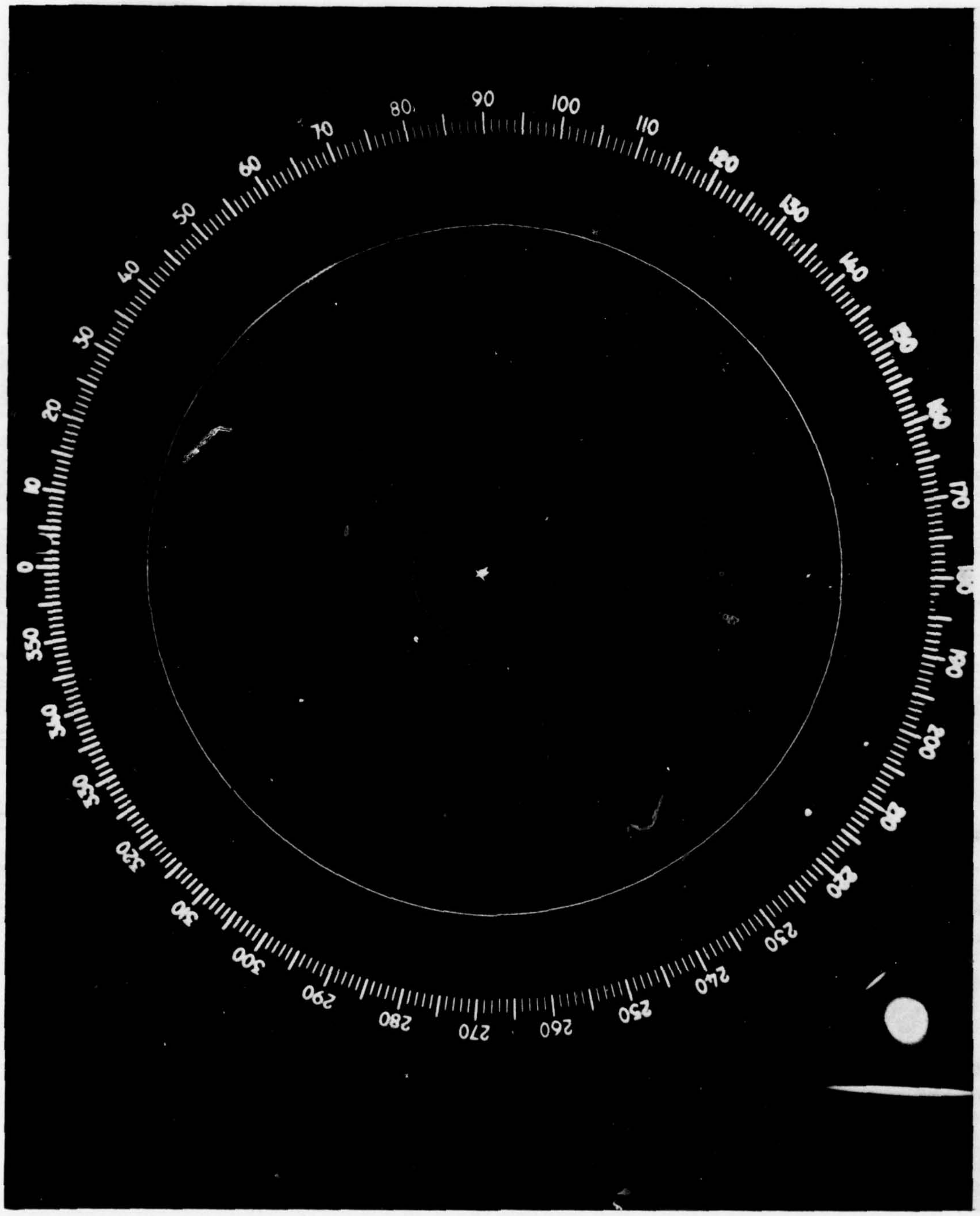


FIGURE 15. 45 SCANS SCENARIO BEACON TRACKS

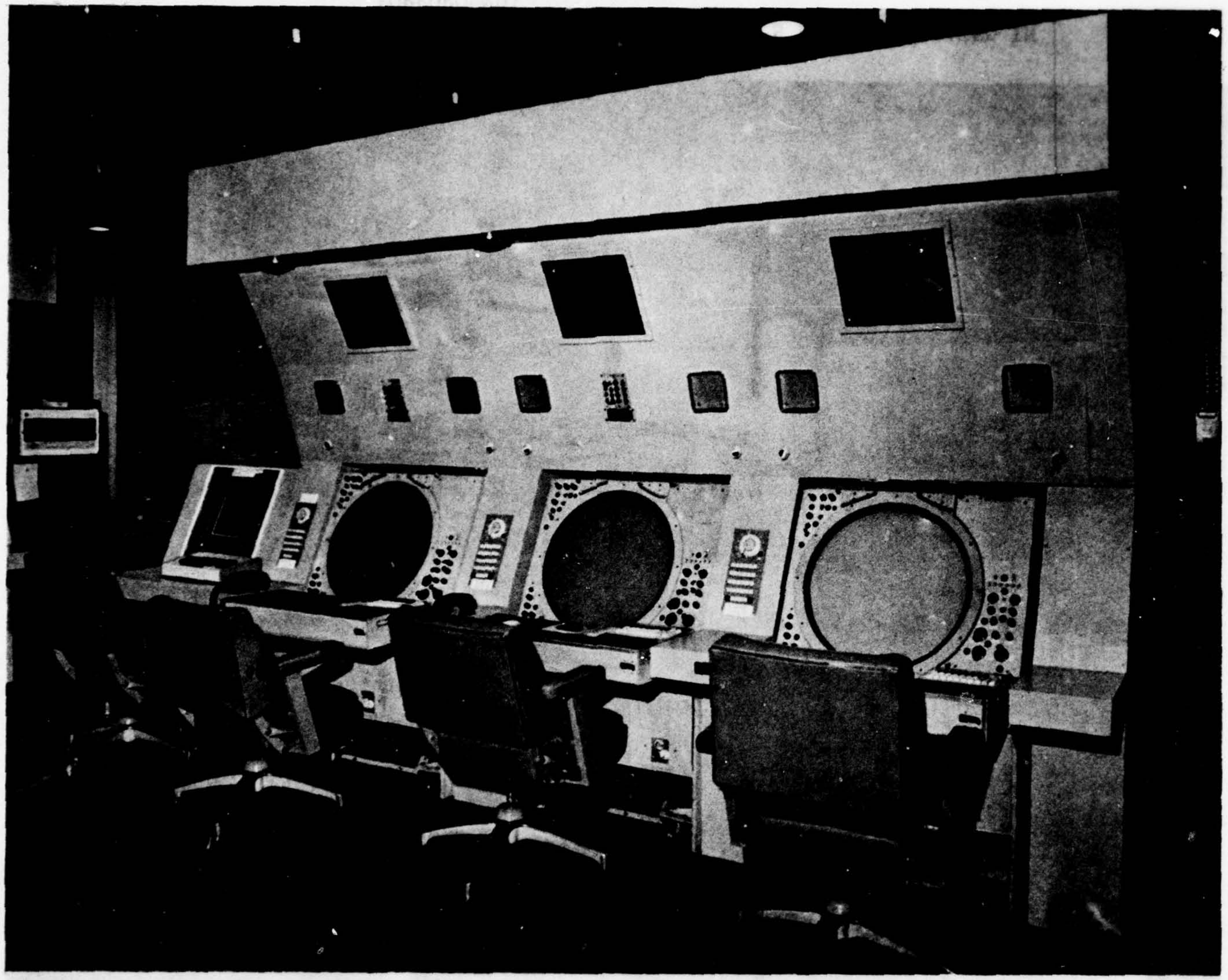


FIGURE 16. TEST CONSOLES (LEFT TWO DISPLAYS USED FOR TESTING)

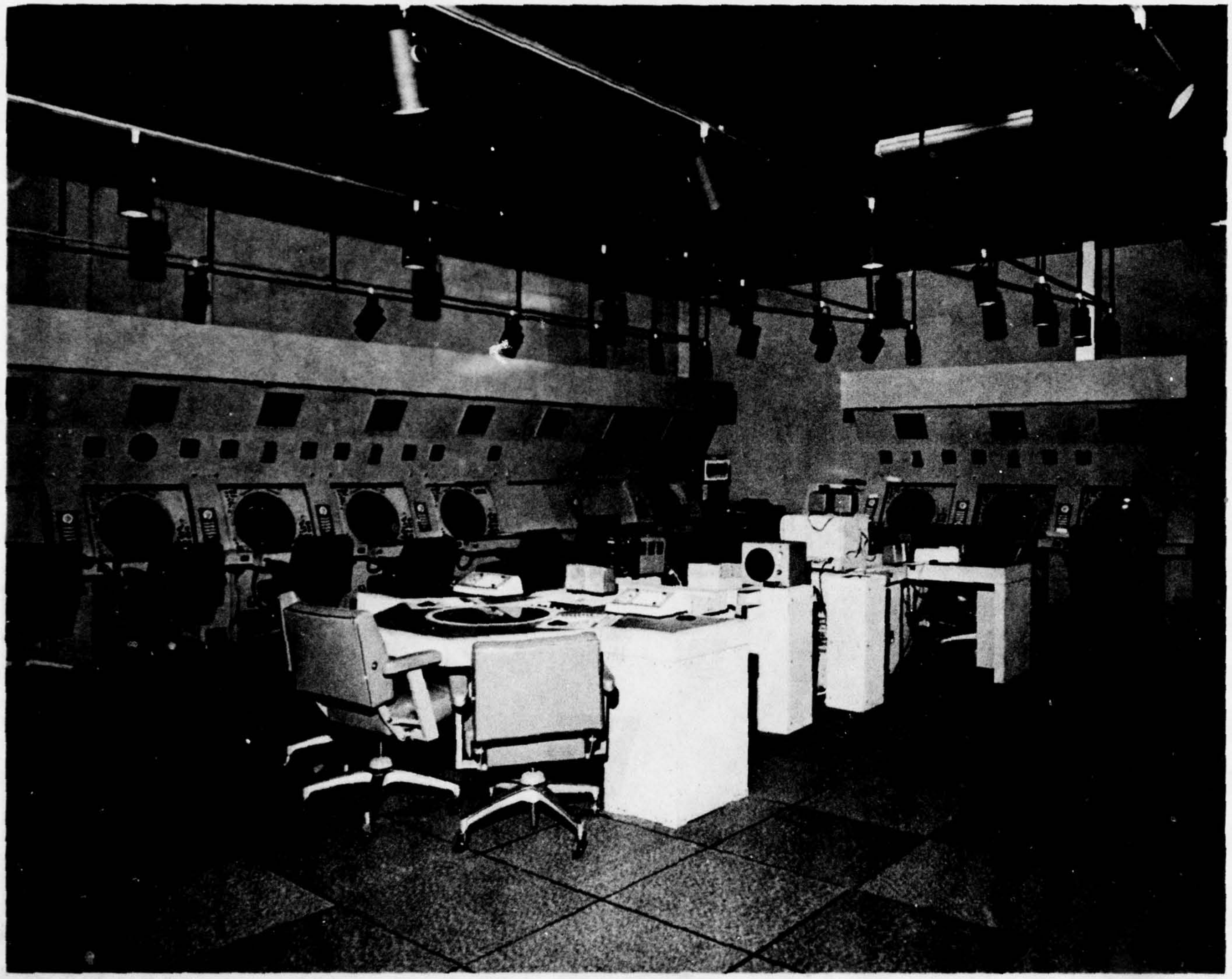


FIGURE 17. TEST AREA (PROJECT CONTROLLER'S DISPLAY LOCATED IN FOREQROUND)

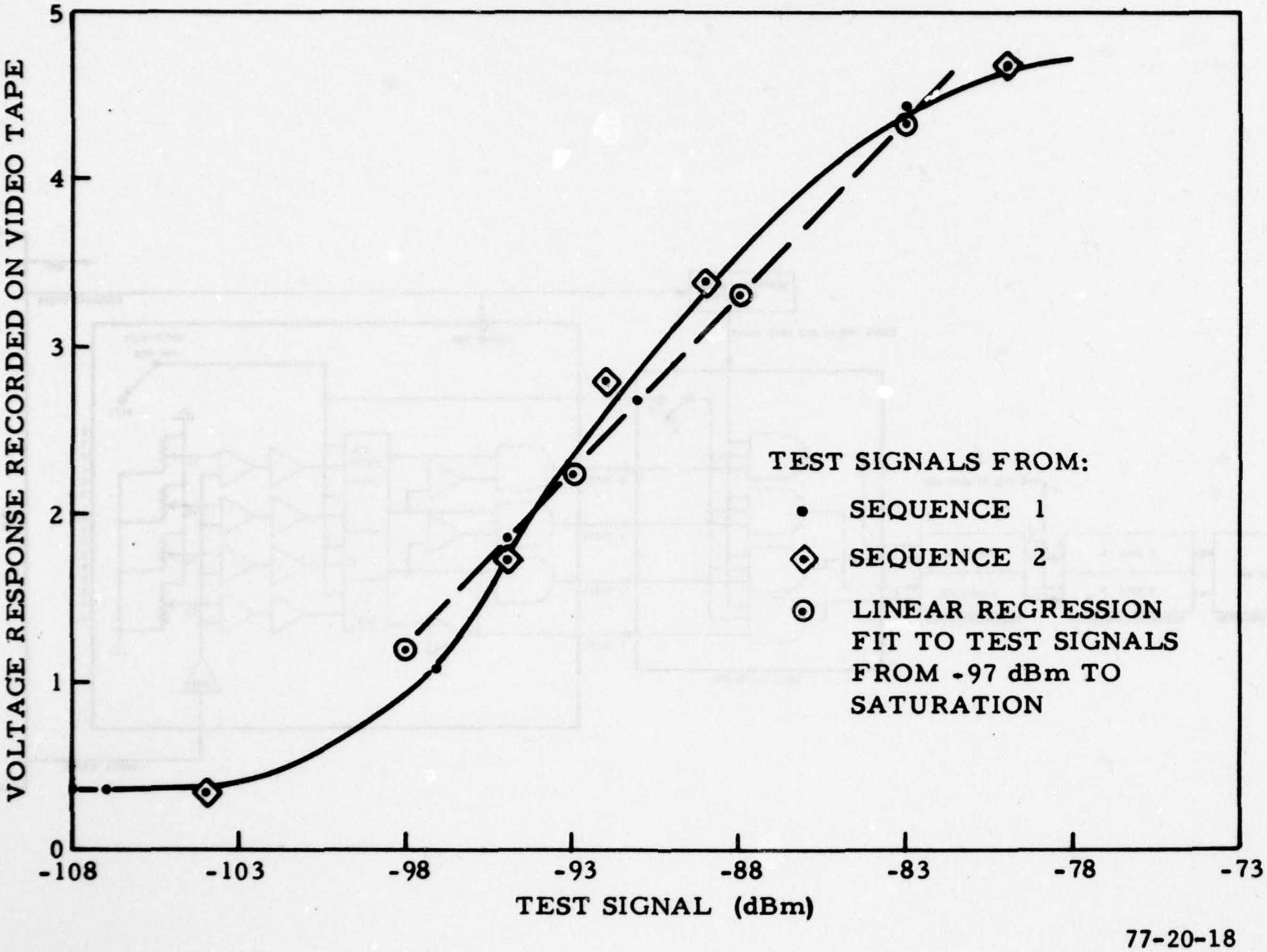


FIGURE 18. RECEIVER RESPONSE CURVE

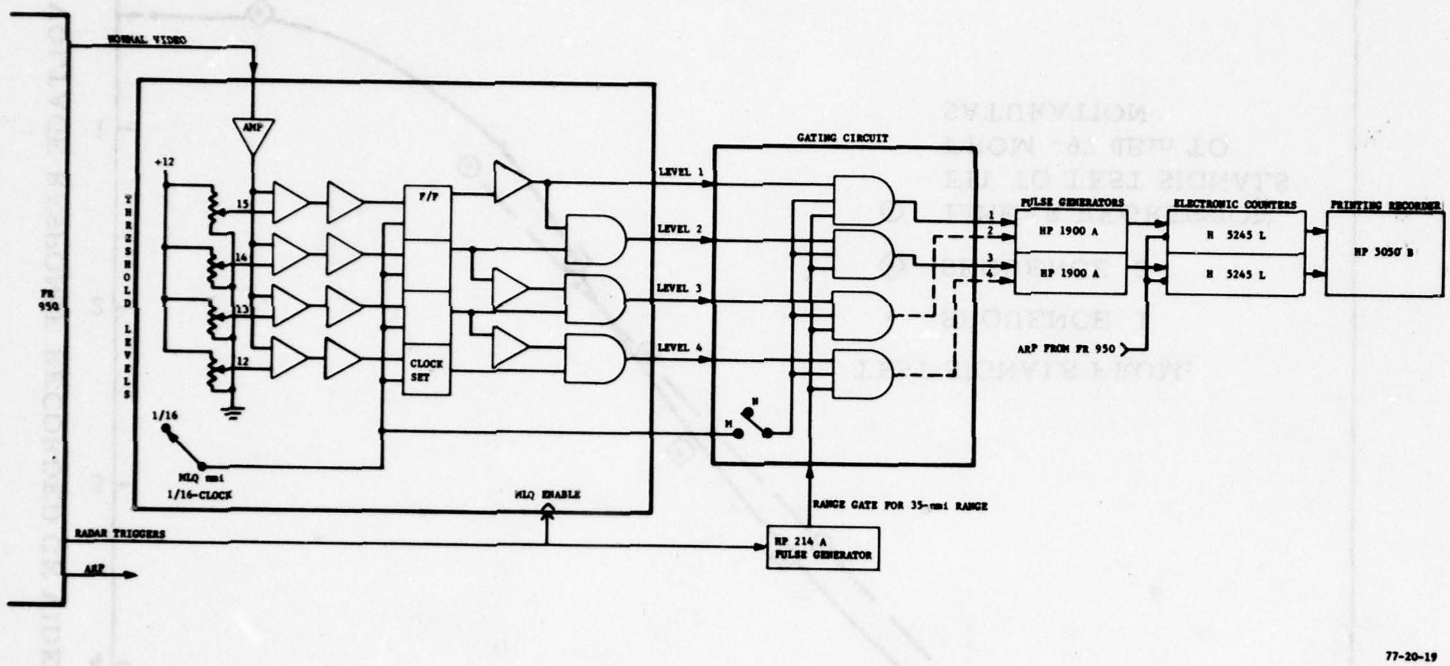


FIGURE 19. GATING CIRCUIT FOR DETERMINING INDICES

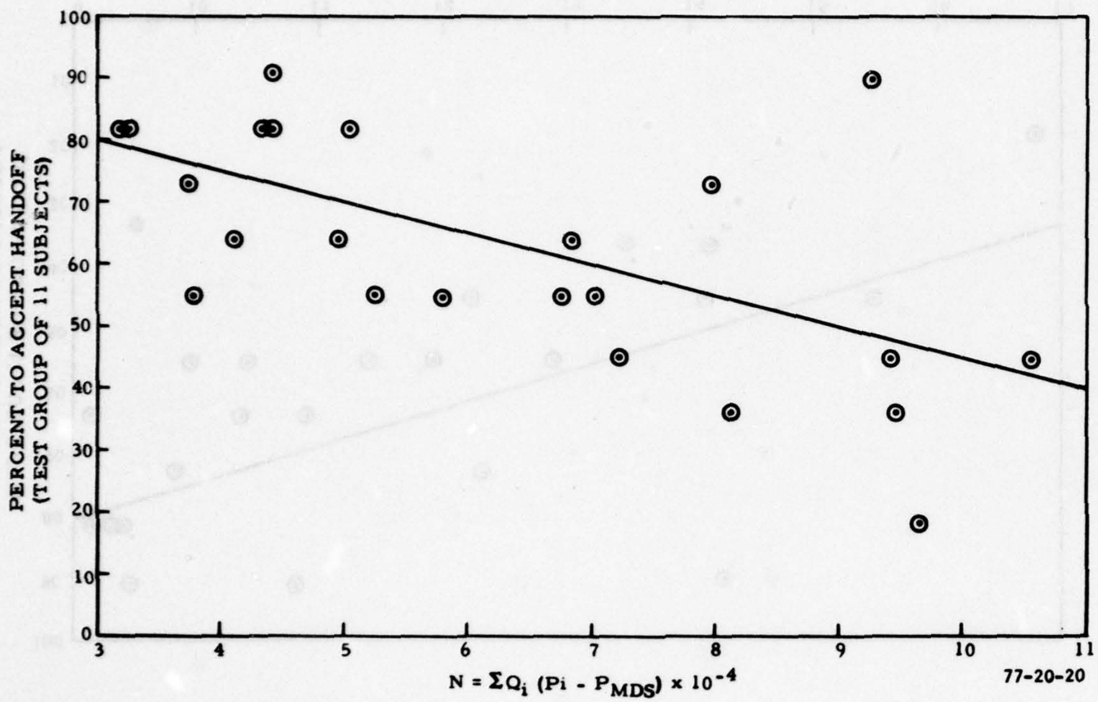


FIGURE 20. PERCENT OF CONTROLLERS TO ACCEPT HANDOFF VERSUS N

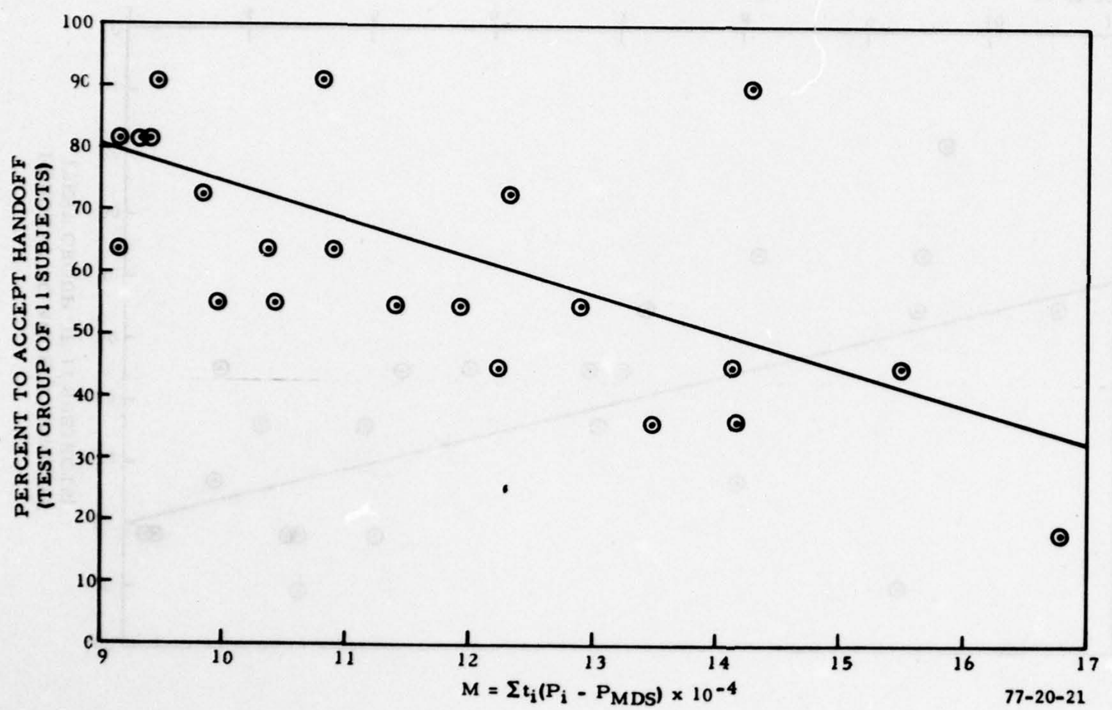


FIGURE 21. PERCENT OF CONTROLLERS TO ACCEPT HANDOFF VERSUS M

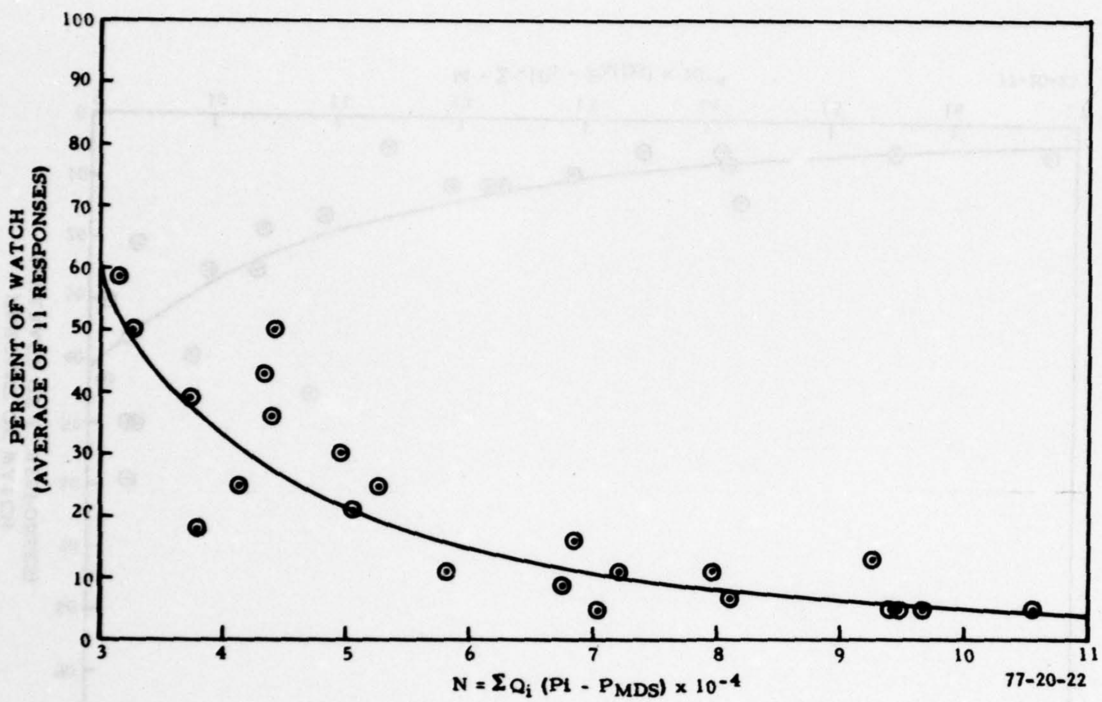


FIGURE 22. PERCENT OF WATCH CONSTANT INTERFERENCE WOULD BE TOLERATED VERSUS N

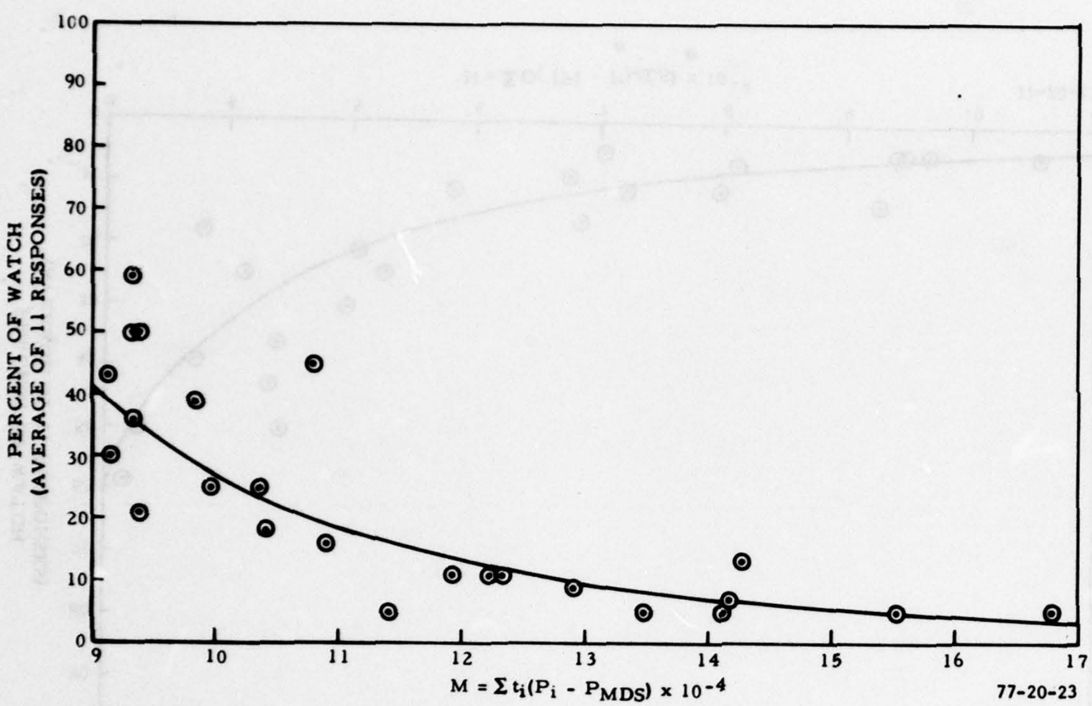


FIGURE 23. PERCENT OF WATCH CONSTANT INTERFERENCE WOULD BE TOLERATED VERSUS M

APPENDIX A

DETERMINATION OF THE N AND M INTERFERENCE INDICES

The following examples have been included to demonstrate the calculation procedures for the N and M numbers used in this report.

After the receiver response curve has been linearized as shown in figure 18, a series of power bins are established ranging from just below the level of single pulse sensitivity to the point of saturation. Single pulse sensitivity is normally set at 12 dB above minimum discernable signal (mds), in this case mds is equal to -108 dBm. The power bin values are then generated thusly:

Power Bin Ranges (dBm)	Midpoint (dBm)	-SPS	Power above SPS (dBm)=(P_i-P_{mds})
-83 to all higher levels	-83	-96	13
-88 to -83	-85.5	-96	10.5
-83 to -88	-90.5	-96	5.5
-98 to -93	-95.5	-96	0.5

Note that the highest power bin covers receiver saturation, -83 dBm to all higher values. The midpoint value is, therefore, set at the point of saturation.

The above power bin values are now used in the N and M tables.

Calculation of N:

Case: 931 prf, 12 dB attenuation, tape sequence 1 (table A-1):

P_i-P_{mds} Power Bin Value (dB)	Q_i 30-33 Scan Average of Pulses in Power Bin	S_i Standard Deviation of Pulse Counts	$Q_i(P_i\text{-}P_{mds})$	$(P_i\text{-}P_{mds})\times S_i$
13	226.20	12.87	2940.6	167.3
10.5	4766.97	90.42	50053.2	949.4
5.5	6219.29	128.32	34206.1	705.8
0.5	10971.10	112.37	5485.6	56.2

In the above table the standard deviation was conservatively estimated by the sample form:

$$S = \sqrt{\frac{\Sigma(x_i-\bar{x})^2}{n-1}}$$

This convention was also followed in the calculations for M. The N value is now determined from the expression:

$$N = \sum_i Q_i \; (P_i\text{-}P_{mds}) \; x10^{-4} = 9.269$$

TABLE A-1. POWER BIN PULSE COUNTS FOR DETERMINATION OF N VALUES

	PRF/Attenuation Case	P_i-P_{mds} Power Bin Value (dB)	Q_i 30-33 Scan Average of Pulses in Power Bin	S_i Standard Deviation of Pulse Counts
Tape 1	931/12	13.0	226.20	12.87
		10.5	4766.97	90.42
		5.5	6219.29	128.32
		0.5	10971.10	112.37
	1150/24	13.0	83.50	9.42
		10.5	3894.59	98.66
		5.5	5812.71	90.51
		0.5	11841.45	94.78
	1013/48	13.0	1.72	1.53
		10.5	2642.10	99.45
		5.5	2498.97	95.31
		0.5	5297.28	68.51
	931/36	13.0	10.16	3.19
		10.5	2806.91	49.71
		5.5	3199.66	79.94
		0.5	6825.50	75.51
Tape 2	1013/12	13.0	258.48	17.10
		10.5	4775.47	119.23
		5.5	6348.86	117.11
		0.5	11438.76	98.24
	1013/24	13.0	51.37	10.78
		10.5	3409.76	91.67
		5.5	5211.53	104.68
		0.5	10056.09	82.29
	931/24	13.0	43.85	6.73
		10.5	3392.18	81.49
		5.5	4990.63	84.23
		0.5	9582.38	66.50
	1150/12	13.0	318.52	23.96
		10.5	5273.42	86.74
		5.5	7235.10	87.43
		0.5	12630.39	169.79
	1013/36	13.0	8.38	2.83
		10.5	2564.38	67.77
		5.5	3479.44	87.37
		0.5	7024.88	80.74
TAPE 3	931/48	13.0	1.94	1.78
		10.5	2517.22	98.79
		5.5	2608.35	64.85
		0.5	5126.29	231.68
	1150/36	13.0	12.69	3.86
		10.5	2721.69	66.68
		5.5	3666.38	103.47
		0.5	7588.78	84.28

TABLE A-1. POWER BIN PULSE COUNTS FOR DETERMINATION OF N VALUES (Continued)

	PRF/Attenuation Case	P_i-P_{mds} Power Bin Value (dB)	Q_i 30-33 Scan Average of Pulses in Power Bin	S_i Standard Deviation of Pulse Counts
	1150/48	13.0	3.97	2.82
		10.5	2554.97	77.67
		5.5	2635.30	93.80
		0.5	5366.70	52.26
Tape 4	1013/48	13.0	DATA NOT AVAILABLE FROM TAPE	
		10.5		
		5.5		
		0.5		
	1013/12	13.0	264.29	47.04
		10.5	3589.57	240.18
		5.0	6224.59	70.61
		0.5	11392.07	118.72
	931/24	13.0	66.07	6.75
		10.5	3869.65	475.75
		5.5	4718.77	62.67
		0.5	9581.45	106.86
	931/12	13.0	234.74	12.57
		10.5	5059.70	73.93
		5.5	5985.41	77.95
		0.5	11212.14	74.58
Tape 5	1013/24	13.0	66.78	0.21
		10.5	1735.94	63.78
		5.5	6169.00	106.57
		0.5	9989.90	112.06
	1150/12	13.0	383.94	24.09
		10.5	3775.60	100.53
		5.5	8282.13	69.63
		0.5	12907.48	497.33
	1013/36	13.0	10.22	3.44
		10.5	922.90	63.20
		5.5	4447.29	102.21
		0.5	7232.03	198.16
	1150/36	13.0	13.53	4.24
		10.5	1018.63	63.19
		5.5	4795.10	79.31
		0.5	8014.87	148.18
	1150/24	13.0	93.81	8.82
		10.5	2109.41	97.68
		5.5	7007.00	98.06
		0.5	11673.38	182.47
Tape 6	931/36	13.0	9.47	3.75
		10.5	1126.53	76.19
		5.5	4053.06	42.83
		0.5	6626.38	121.04
	1150/48	13.0	3.59	2.11
		10.5	1033.00	63.23
		5.5	3479.25	75.65
		0.5	5414.03	143.42
	931/48	13.0	3.48	2.54
		10.5	1053.91	60.95
		5.5	3294.94	54.36
		0.5	5059.94	109.18

Standard deviation for the resultant N was established by the form:

$$S = \sqrt{\sum_i S_i^{\,2}} \times 10^{-4} = 0.1196$$

Calculation of M:

Case: 931 prf, 12 dB attenuation, tape sequence 1 (table A-2):

P_i-P_{mds} Power Bin Value (dB)	t_i* 30-33 Scan Average time that Power Bins Were Filled	S_i Standard Deviation of Time Power Bins Were Filled	$t_i(P_i-P_{mds})$	$(P_i-P_{mds})xS_i$
13	7084.93	117.08	92104.1	1522.0
10.5	2513.45	79.34	26391.2	833.1
5.5	3611.39	67.90	19862.6	373.4
0.5	9250.13	173.44	4625.1	86.7

$$M = \sum_i t_i\,(P_i-P_{mds}) \times 10^{-4} = 14.298$$

$$s_m = \sqrt{\sum_i s_i^2} \times 10^{-4} = 0.178$$

*Time estimated by 1/16 n mile clock pulses.

TABLE A-2. POWER BIN TIME COUNTS FOR DETERMINATION OF M VALUES

	PRF/Attenuation Case	P_i-P_{mds} Power Bin Value (dB)	t_i* Scan Average of time that Power Bins Were Filled	S_i Deviation of time Power Bins Were Filled
Tape 1	931/12	13.0	7084.93	117.08
		10.5	2513.45	79.34
		5.5	3611.39	67.90
		0.5	9250.13	173.44
	1150/24	13.0	6570.00	46.69
		10.5	1388.87	36.84
		5.5	3345.50	61.88
		0.5	10210.81	162.24
	1013/48	13.0	6628.42	135.59
		10.5	180.81	26.69
		5.5	829.38	33.29
		0.5	2925.06	112.05
	931/36	13.0	6622.52	95.81
		10.5	339.69	24.36
		5.5	373.29	56.34
		0.5	4613.29	115.53
Tape 2	1013/12	13.0	6799.47	145.73
		10.5	2622.31	71.70
		5.5	3681.63	88.76
		0.5	10078.27	172.15
	1013/24	13.0	6237.48	97.33
		10.5	1247.87	45.86
		5.5	2882.17	74.33
		0.5	8453.50	171.67
	931/24	13.0	6125.06	118.19
		10.5	1090.09	60.44
		5.5	2564.27	77.79
		0.5	7692.78	135.15
	1150/12	13.0	7194.74	86.25
		10.5	3025.97	80.72
		5.5	4399.06	102.72
		0.5	11319.68	200.26
	1013/36	13.0	5955.97	138.35
		10.5	336.21	25.48
		5.5	1506.19	54.34
		0.5	4800.35	128.45
Tape 3	931/48	13.0	6487.45	77.62
		10.5	162.94	17.39
		5.5	761.90	27.23
		0.5	2938.79	63.69
	1150/36	13.0	6478.97	170.66
		10.5	353.41	17.30
		5.5	1642.48	102.37
		0.5	5952.48	221.54
	1150/48	13.0	6590.03	86.64
		10.5	174.79	18.81
		5.5	799.35	48.48
		0.5	3384.30	82.71
Tape 4	1013/48	13.0	7218.19	994.18
		10.5	735.06	103.05
		5.5	1224.24	237.30
		0.5	3949.00	825.05

TABLE A-2. POWER BIN TIME COUNTS FOR DETERMINATION OF M VALUES (Continued)

	PRF/Attenuation Case	$P_i - P_{mds}$ Power Bin Value (dB)	t_i* Scan Average of time that Power Bins Were Filled	S_i Deviation of time Power Bins Were Filled
	1013/12	13.0	6592.67	117.64
		10.5	2836.03	72.49
		5.5	3883.06	78.26
		0.5	10019.22	146.79
	931/24	13.0	6200.97	319.73
		10.5	1288.54	129.06
		5.5	3909.03	968.97
		0.5	13829.86	4627.79
	931/12	13.0	6262.38	106.25
		10.5	2601.47	76.60
		5.5	3786.67	72.68
		0.5	10654.00	729.62
Tape 5	1013/24	13.0	6172.63	86.21
		10.5	1753.06	61.80
		5.5	2964.84	80.62
		0.5	8970.62	282.47
	1150/12	13.0	7371.78	113.44
		10.5	3829.81	89.76
		5.5	4721.50	79.22
		0.5	11971.53	384.31
	1013/36	13.0	6335.12	148.10
		10.5	901.42	48.16
		5.5	1768.46	63.43
		0.5	5498.25	197.91
	1150/36	13.0	6083.41	124.35
		10.5	1005.44	40.02
		5.5	2011.42	63.68
		0.5	6368.87	158.99
	1150/24	13.0	6342.63	93.95
		10.5	2085.84	65.06
		5.5	3568.31	83.04
		0.5	10299.00	211.10
Tape 6	931/36	13.0	6141.06	92.09
		10.5	824.75	54.94
		5.5	1421.33	49.63
		0.5	4472.44	102.51
	1150/48	13.0	6146.61	80.41
		10.5	664.75	42.75
		5.5	1055.47	45.24
		0.5	3194.32	187.60
	931/48	13.0	6146.61	88.70
		10.5	686.06	67.86
		5.5	908.69	33.17
		0.5	2857.81	113.42

*Time estimated by 1/16 nmi clock pulses.

APPENDIX B

PREDICTION OF THE N INDEX

The following example demonstrates a method for calculating the interference index number N based on a four level model of an antenna pattern. The pattern itself consists of a mainbeam, first and second sidelobes, as well as backlobes. The relative gains used for this example are:

First sidelobe = 20 dB down from mainbeam
Second sidelobe = 30 dB down from mainbeam
Backlobe = 10 dB_i and represents the median gain of the antenna.

The basis for deriving the interference index is the interference to single pulse sensitivity ratio:

$$I/_R = P_t + G_m - L_p - OFR - R_s \leq 0dB$$

Where:

$I/_R$ = Interference to single pulse sensitivity (dB)
P_t = Transmit power of the interfering radar (dBm)
G_m = Antenna mutual gain of the interferer - victim pair (dB_i)
L_p = Propagation loss (dB)
OFR = Off frequency correction factor (dB)
R_s = Single pulse sensitivity of the victim radar, nominally set at 12dB above mds.

Since the concern here is to demonstrate the general antenna coupling phenomena, no treatment is provided on the propagation terms. These subjects have, however, been dealt with by other authors (reference 12).

The four level antenna pattern, exemplified in figure B-1, has the mainbeam angle defined by the 3 dB points of the beam. The first sidelobe covers the total angle between the peaks of the first sidelobes, while the second sidelobes extend through 180 degrees of the antenna pattern. The backlobe extends through the back 180 degrees of the pattern. These conventions are of course arbitrary but are adequate for the current demonstration.

The gain for each level of the victim and interfering antennas are first determined. This will most easily be obtained from a horizontal antenna plot generated at an antenna range, or by using suitable field measurements.

A table is then generated with the probability of occurrence of each level for both antennas. In the following table the notation convention is as follows:

m: main beam
s_1: first sidelobe
s_2: second sidelobe
b: backlobe
"-": denotes victim - interferer coupling mode with the vistim proceeding the interferer.

VICTIM

Level	Gain (dB)	Angle at Gain (degree)	Probability of Occurrence (%)
m	34	1.5	0.417
s_1	14	12.5	3.472
s_2	4	166.0	46.111
b	-10	180.0	50.000

INTERFERER

Level	Gain (dB)	Angle at Gain (degree)	Probability of Occurrence (%)
m	28	2.5	0.694
s_1	8	14.5	4.028
s_2	- 2	163.0	45.278
b	-10	180.0	50.000

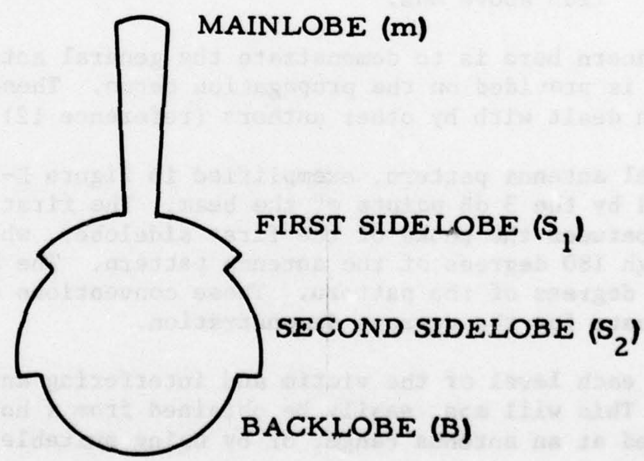


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FIGURE B-1. FOUR LEVEL ANTENNA PATTERN

The probability of occurrence is merely the percentage of the antenna pattern at which a given gain exists. It is now necessary to calculate the respective gains that would exist for the various level combinations of the two antennas. This is readily done by first writing down all possible combinations in descending order based on their respective gains.

Coupling Combination	Gain (dB)	Probability of Occurrence (%)	Cumulative Distribution
m-m	62	0.003	0.00
m-s_1 and s_1-m	42	0.041	0.00
m-s_2 and s_2-m	32	0.509	0.04
m-b	24	0.209	0.55
s_1-s_1	22	0.140	0.76
b-m	18	0.347	0.90
s_1-s_2 and s_2-s_1	12	3.429	1.25
s_1-b	4	1.736	4.68
s_2-s_2	2	20.878	6.41
b-s_1	- 2	2.014	27.29
s_2-b	- 6	23.056	29.31
b-s_2	-12	22.639	52.36
b-b	-20	25.000	75.00

In the preceding table, several combinations have been paired where the resulting gains were equal, e.g., the victim's main beam and interferer's first sidelobe pairs with the victim's first sidelobe and interferer's main beam. The probability of occurrence is the product of the occurrence probabilities for victim and interferer's coupling modes, thus the probability for the m-b combination is: (.00417) x (.50000) x 100 = .509).

In the cases where two modes have the same gain and are paired, the probability of occurrence is the sum of the probabilities of the individual coupling modes.

At this point, a cumulative distribution table is generated for the two antenna systems. This is done by subtracting the probability for the lowest coupling combination gain from 100. The probability for the next higher gain is then subtracted from the first result. This procedure is continued until all coupling modes have been accounted for. Ideally, the cumulative distribution up to and including mainbeam-to-mainbeam coupling will give a value of 0.00. This means that no gain levels will exceed 62 dB_i in this example. Roundoffs in calculations will show a slight discrepancy at this point. The resulting points are then plotted on probability paper as shown in figure B-2.

Once the cumulative probability curve has been generated, the gain required for interference to appear on a display must be determined. If we assume that the transmit power is 87 dBm, the propagation loss is 147 dB, off frequency rejection is 50 dB, and the single pulse sensitivity is -100 dBm; then the mutual gain must exceed +10 dB_i for interference to be seen by an operator. If the victim receiver has a 25 dB dynamic range extending from -100 dBm to -85 dBm, and the single pulse sensitivity is -100 dBm, then the

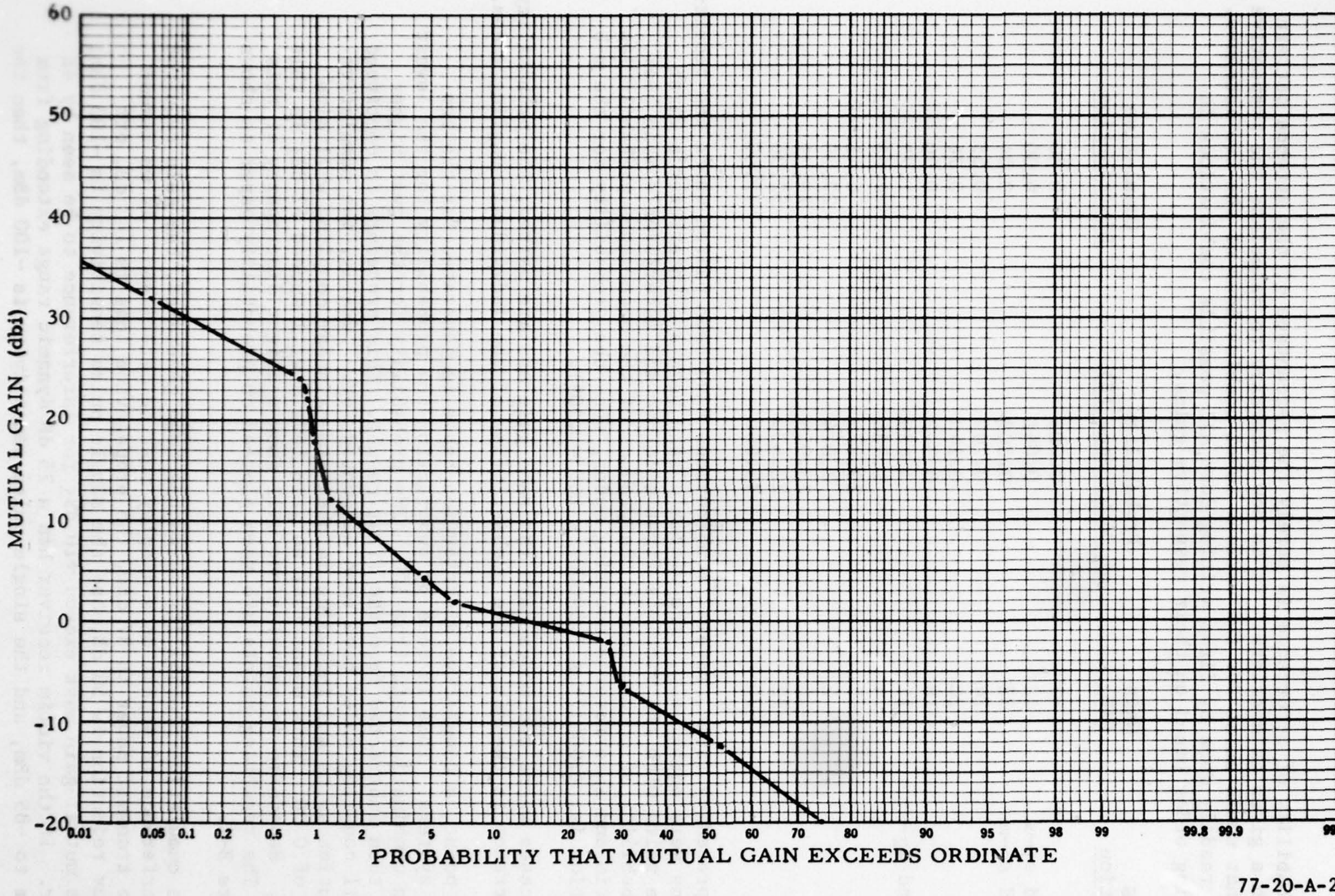

FIGURE B-2. CUMULATIVE DISTRIBUTION OF THE MUTUAL GAIN FOR TWO FOUR LEVEL ANTENNAS

resulting power range available for division into bins is 15 dB. Two power bins of 10 dB each are established ranging from -100 dBm to -80 dBm. The mid-point of each power bin minus the single pulse sensitivity level provides the value associated with all interfering pulses within that bin. Each one of the bins will also represent different ranges of antenna coupling.

Bin Value	Coupling Range (dB_i)	Percentage of Pulses in Coupling Range
5 dB	10 to 20	1.8-0.9 =0.9
15 dB	20 to all higher values	0.9

The percentage of pulses in the coupling range is determined from figure B-2. These numbers are in turn multiplied by the power bin value.

$$.009\ (5\ dB) = 0.045$$
$$.009\ (15\ dB) = 0.135$$

If we assume that the following parameters hold, then the interference index may be calculated.

$PRF_I = 931 \quad PRF_V = 1150$
Rotation Rate of Victim = 4.8 seconds.

Supplying the appropriate values in the expression:

$$N = Q(P_i - P_{mds}) \times 10^{-4}$$
$$N = (.045+0.135)\ (931)\ (4.8) \times 10^{-4}$$
$$= 0.080$$

This can now be adapted to the individual display by calculating the proportion of the display that is being painted.

$$\text{Possible Radar Maximum} = \left(\frac{1}{1150\ \text{pps}}\right)\left(\frac{1}{12.36\ \mu s}\right) = 70.35\ \text{nmi}$$

If the display is nominally set at 35 nmi, then the index number that applies is equal to;

$$\frac{35\text{nmi}}{70.35\text{nmi}}\ (0.080) \cong 0.04$$

The foregoing example demonstrates the idea of how to calculate the N value for a particular interfering condition. Obviously, a more precise method will require more thorough representation of the mutual gain cumulative distribution curve. This can be done by invoking the conclusions of R. C. Johnson (reference 13) which states that knowledge of the cumulative distribution of the antennas involved can be combined to predict the mutual cumulative distribution.

Distributions for the antennas can be obtained hypothetically from range measurements or by actual field measurements. In the one case, plots are available for a single type of antenna thus easing instrumentation and distribution costs at the sacrifice of possible site effects. The other alternative, field measurements could provide the cumulative distribution of various interfering antennas with unknown patterns, but directly incorporating site effects. The tradeoff here is the cost of field instrumentation and the need for complimentary range measurements when an additional radar is proposed for an existing interfering environment.